Technology Roadmap

Smart Grids

International Energy Agency

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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Foreword

Current trends in energy supply and use are patently unsustainable – economically, environmentally and socially. Without decisive action, increased fossil fuel demand will heighten concerns over the security of supplies and energy-related emissions of carbon dioxide (CO_2) will more than double by 2050. We can and must change our current path, but this will take an energy revolution and low-carbon energy technologies will have a crucial role to play. Energy efficiency, many types of renewable energy, carbon capture and storage, nuclear power and new transport technologies will all require widespread deployment if we are to reach our greenhouse-gas emission goals. Every major country and sector of the economy must be involved. The task is also urgent if we are to make sure that investment decisions taken now do not saddle us with sub-optimal technologies in the long term.

There is a growing awareness of the urgent need to turn political statements and analytical work into concrete action. To spark this movement, at the request of the G8, the International Energy Agency (IEA) is developing a series of roadmaps for some of the most important technologies. These roadmaps provide solid analytical footing that enables the international community to move forward on specific technologies. Each roadmap develops a growth path for a particular technology from today to 2050, and identifies technology, financing, policy and public engagement milestones that need to be achieved to realise the technology's full potential. Roadmaps also include a special focus on technology development and diffusion to emerging economies. International collaboration will be critical to achieve these goals.

To date, much of the of low-carbon technology analysis in the energy sector has focused on power generation and end-use technologies. This roadmap focuses on smart grids – the infrastructure that enables the delivery of power from generation sources to end-uses to be monitored and managed in real time. Smart grids are required to enable the use of a range of low-carbon technologies, such as variable renewable resources and electric vehicles, and to address current concerns with the electricity system infrastructure, such as meeting peak demand with an ageing infrastructure. Unlike most other low-carbon energy technologies, smart grids must be deployed in both existing systems (which in some cases are over 40 years old) as well as within totally new systems. Smart grid technologies must also be installed with minimum disruption to the daily operation of the electricity system. These challenges do not detract, however, from the opportunity to gain significant benefits from developing and deploying smart grids.

Nevertheless, significant barriers must be overcome in order to deploy smart grids at the scale they are needed. Governments need to establish clear and consistent policies, regulations and plans for electricity systems that will allow innovative investment in smart grids. It will also be vital to gain greater public engagement, and this will be helped educating all relevant stakeholders – but especially customers and consumer advocates – about the need for smart grids and the benefits they offer. Achieving the vision of smartening the grid between now and 2050 requires governments, research organisations, industry, the financial sector and international organisations to work together. This roadmap sets out specific steps they need to take over the coming years to achieve milestones that will allow smart grids to deliver a clean energy future.

Nobuo Tanaka
Executive Director, IEA

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Figure 4, page 11: the values for Africa and Central South America in 2050 have been corrected to 25% and 18% respectively.

Page 20: the following paragraph is inserted under the heading "Smart grid demonstration and deployment efforts" following the second paragraph and preceding the third paragraph:

The Telegestore project, launched in 2001 by ENEL Distribuzione S.p.A. (i.e. prior to the current smart grids stimulus funding) addresses many of these issues. The project installed 33 million smart meters (including system hardware and software architecture) and automated 100 000 distribution substations, while also improving management of the operating workforce and optimising asset management policies and network investments. The project has resulted in fewer service interruptions, and its EUR 2.1 billion investment has led to actual cost savings of more than EUR 500 million per year. ENEL is continually enhancing the system by introducing new features, technologies and flexibility. The project clearly demonstrates the value of a large-scale, integrated deployment of smart grid technologies to solve existing problems and plan for future needs.

This roadmap was prepared in April 2011. It was drafted by the International Energy Agency's Energy Technology Policy Division. This paper reflects the views of the International Energy Agency (IEA) Secretariat, but does not necessarily reflect those of IEA member countries. For further information, please contact the author at: david.elzinga@iea.org.

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Acknowledgements

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Key findings

- The development of smart grids is essential if the global community is to achieve shared goals for energy security, economic development and climate change mitigation. Smart grids enable increased demand response and energy efficiency, integration of variable renewable energy resources and electric vehicle recharging services, while reducing peak demand and stabilising the electricity system.
- The physical and institutional complexity of electricity systems makes it unlikely that the market alone will implement smart grids on the scale that is needed. Governments, the private sector, and consumer and environmental advocacy groups must work together to define electricity system needs and determine smart grid solutions.
- Rapid expansion of smart grids is hindered by a tendency on the part of governments to shy away from taking ownership of and responsibility for actively evolving or developing new electricity system regulations, policy and technology. These trends have led to a diffusion of roles and responsibilities among government and industry actors, and have reduced overall expenditure on technology development and demonstration, and policy development. The result has been slow progress on a number of regional smart grid pilot projects that are needed.
- The "smartening" of grids is already happening; it is not a one-time event. However, large-scale, system-wide demonstrations are urgently needed to determine solutions that can be deployed at full scale, integrating the full set of smart grid technologies with existing electricity infrastructure.
- Large-scale pilot projects are urgently needed in all world regions to test various business models and then adapt them to the local circumstances. Countries and regions will use smart grids for different purposes; emerging economies may leapfrog directly to smart electricity infrastructure, while OECD countries are already investing in incremental improvements to existing grids and small-scale pilot projects.
- Current regulatory and market systems can hinder demonstration and deployment of smart grids. Regulatory and market models – such as those addressing system investment, prices and customer participation – must evolve as technologies offer new options over the course of long-term, incremental smart grid deployment.
- Regulators and consumer advocates need to engage in system demonstration and deployment to ensure that customers benefit from smart grids. Building awareness and seeking consensus on the value of smart grids must be a priority, with energy utilities and regulators having a key role in justifying investments.
- Greater international collaboration is needed to share experiences with pilot programmes, to leverage national investments in technology development, and to develop common smart grid technology standards that optimise and accelerate technology development and deployment while reducing costs for all stakeholders.
- Peak demand will increase between 2010 and 2050 in all regions. Smart grids deployment could reduce projected peak demand increases by 13% to 24% over this frame for the four regions analysed in this roadmap.
- Smart grids can provide significant benefits to developing countries. Capacity building, targeted analysis and roadmaps – created collaboratively with developed and developing countries – are required to determine specific needs and solutions in technology and regulation.

Introduction

There is a pressing need to accelerate the development of low-carbon energy technologies in order to address the global challenges of energy security, climate change and economic growth. Smart grids are particularly important as they enable several other low-carbon energy technologies, including electric vehicles, variable renewable energy sources and demand response. This roadmap provides a consensus view on the current status of smart grid technologies, and maps out a global path for expanded use of smart grids, together with milestones and recommendations for action for technology and policy development.

What are smart grids?

A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability.

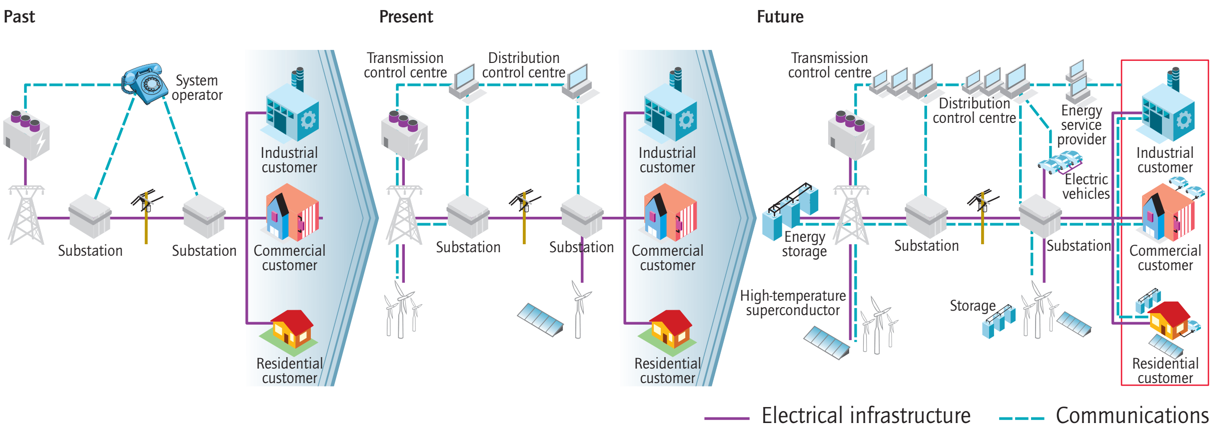
For the purposes of this roadmap, smart grids include electricity networks (transmission and distribution systems) and interfaces with generation, storage and end-users.[1] While many regions have already begun to "smarten" their electricity system, all regions will require significant additional investment and planning to achieve a smarter grid. Smart grids are an evolving set of technologies that will be deployed at different rates in a variety of settings around the world, depending on local commercial attractiveness, compatibility with existing technologies, regulatory developments and investment frameworks. Figure 1 demonstrates the evolutionary character of smart grids.

Rationale for smart grid technology

The world's electricity systems face a number of challenges, including ageing infrastructure, continued growth in demand, the integration of increasing numbers of variable renewable energy sources and electric vehicles, the need to improve the security of supply and the need to lower carbon emissions. Smart grid technologies offer ways not just to meet these challenges but also to develop a cleaner energy supply that is more energy efficient, more affordable and more sustainable.

1 Smart grid concepts can be applied to a range of commodity infrastructures, including water, gas, electricity and hydrogen. This roadmap focuses solely on electricity system concepts.

Figure 1. Smarter electricity systems



Source: Unless otherwise indicated, all material derives from IEA data and analysis.

KEY POINT: The "smartening" of the electricity system is an evolutionary process, not a one-time event.

These challenges must also be addressed with regard to each region's unique technical, financial and commercial regulatory environment. Given the highly regulated nature of the electricity system, proponents of smart grids must ensure that they engage with all stakeholders, including equipment manufacturers, system operators, consumer advocates and consumers, to develop tailored technical, financial and regulatory solutions that enable the potential of smart grids (Figure 2).

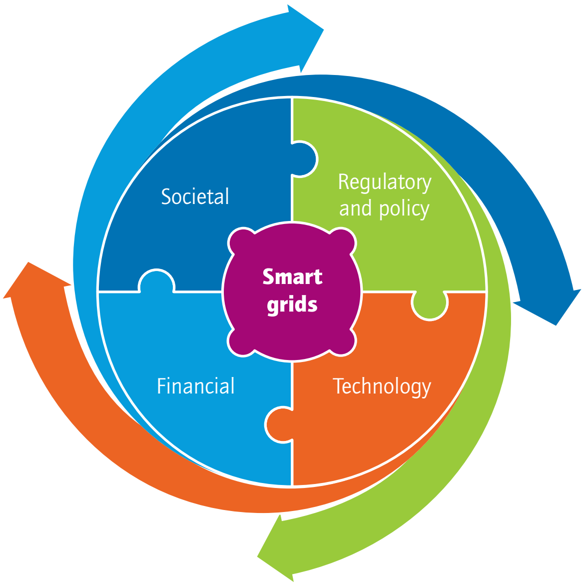
The main characteristics of smart grids are explained in Table 1.

Table 1. Characteristics of smart grids

Characteristic	*Description*
Enables informed participation by customers	Consumers help balance supply and demand, and ensure reliability by modifying the way they use and purchase electricity. These modifications come as a result of consumers having choices that motivate different purchasing patterns and behaviour. These choices involve new technologies, new information about their electricity use, and new forms of electricity pricing and incentives.
Accommodates all generation and storage options	A smart grid accommodates not only large, centralised power plants, but also the growing array of customer-sited distributed energy resources. Integration of these resources – including renewables, small-scale combined heat and power, and energy storage – will increase rapidly all along the value chain, from suppliers to marketers to customers.
Enables new products, services and markets	Correctly designed and operated markets efficiently create an opportunity for consumers to choose among competing services. Some of the independent grid variables that must be explicitly managed are energy, capacity, location, time, rate of change and quality. Markets can play a major role in the management of these variables. Regulators, owners/operators and consumers need the flexibility to modify the rules of business to suit operating and market conditions.
Provides the power quality for the range of needs	Not all commercial enterprises, and certainly not all residential customers, need the same quality of power. A smart grid supplies varying grades (and prices) of power. The cost of premium power-quality features can be included in the electrical service contract. Advanced control methods monitor essential components, enabling rapid diagnosis and solutions to events that impact power quality, such as lightning, switching surges, line faults and harmonic sources.
Optimises asset utilisation and operating efficiency	A smart grid applies the latest technologies to optimise the use of its assets. For example, optimised capacity can be attainable with dynamic ratings, which allow assets to be used at greater loads by continuously sensing and rating their capacities. Maintenance efficiency can be optimised with condition-based maintenance, which signals the need for equipment maintenance at precisely the right time. System-control devices can be adjusted to reduce losses and eliminate congestion. Operating efficiency increases when selecting the least-cost energy-delivery system available through these types of system-control devices.
Provides resiliency to disturbances, attacks and natural disasters	Resiliency refers to the ability of a system to react to unexpected events by isolating problematic elements while the rest of the system is restored to normal operation. These self-healing actions result in reduced interruption of service to consumers and help service providers better manage the delivery infrastructure.

Source: Adapted from DOE, 2009.

Figure 2. Smart grids can link electricity system stakeholder objectives



KEY POINT: Smart grids provide an opportunity to link societal, financial, technology and regulatory and policy objectives.

Purpose, process and structure of the roadmap

To provide guidance to government and industry stakeholders on the technology pathways needed to achieve energy security, economic growth and environmental goals, the IEA is developing a series of global low-carbon energy roadmaps covering a range of technologies. The roadmaps are guided by the IEA *Energy Technology Perspectives* BLUE Map Scenario, which aims to achieve a 50% reduction in energy-related CO_2 emissions by 2050. Each roadmap represents international consensus on milestones for technology development, legal and regulatory needs, investment requirements, public engagement and outreach, and international collaboration.

The Smart Grid Roadmap aims to:

- Increase understanding among a range of stakeholders of the nature, function, costs and benefits of smart grids.
- Identify the most important actions required to develop smart grid technologies and policies that help to attain global energy and climate goals.
- Develop pathways to follow and milestones to target based on regional conditions.

The roadmap was compiled with the help of contributions from a wide range of interested parties, including electricity utilities, regulators, technology and solution providers, consumer

Table 2. Workshop contributions to the Smart Grids Roadmap

Date	*Location*	*Event*	*Workshop topic*
28 April 2010	Paris	ENARD/IEA Joint Workshop	Electricity Networks: A Key Enabler of Sustainable Energy Policy
20-21 May 2010	Paris	Joint GIVAR/Smart Grid Roadmap Workshop	Defining Smart Grid Technologies and RD&D needs
8-9 June 2010	Paris	CERT Meeting	Role of Government and Private Sector in Smart Grid RD&D
23-24 September 2010	Washington, DC	GridWise Global Forum	Smart Grid – Smart Customer Policy
28-29 September 2010	Madrid	ENARD/IEA Joint Workshop	Financing the Smart Grid
8-9 November 2010	Jeju Island, Korea	Korea Smart Grid Week	Developing Country and Emerging Economy Smart Grid Perspectives

Notes: ENARD refers to the IEA implementing agreement on Electricity Networks Analysis, R&D, (www.iea-enard.org). The ENARD/IEA workshops are part of the implementing agreement work plan and, although highly complementary, not directly tied to the smart grid roadmap initiative.

The IEA Grid Integration of Variable Renewables (GIVAR) project is a multi-year initiative that is assessing and quantifying approaches to large-scale deployment of variable renewable generation technologies.

CERT refers to the IEA Committee on Energy Research and Technology.

advocates, finance experts and government institutions. In parallel with its analysis and modelling, the Smart Grid Roadmap team has hosted and participated in several expert workshops (Table 2).

This roadmap does not attempt to cover every aspect of smart grids and should be regarded as a work in progress. As global analysis improves, new data will provide the basis for updated scenarios and assumptions. More important, as the technology, market and regulatory environments evolve, additional tasks will come to light. The broad nature of smart grids requires significant collaboration with other technology areas, including transport electrification, energy storage, generation and end-use. The roadmap provides links to further background information and reading.

The roadmap is organised into seven sections. The first looks at the challenges facing grids today and the benefits that smart grids offer, including electricity reliability. The second describes the current deployment status of smart grids, along with smart grid costs and savings and market and regulatory considerations. The third section outlines a vision for smart grid deployment to 2050 based on the *Energy Technology Perspectives 2010* (*ETP 2010*) BLUE Map Scenario, including an analysis of regional needs. The fourth and fifth sections examine smart grid technologies and policies, and propose actions and milestones for their development and implementation. The sixth section discusses current and future international collaboration, while the seventh section presents an action plan and identifies the next steps that need to be taken.

Electricity system needs for today and the future

Box 1: *Energy Technology Perspectives* scenario descriptions

The ETP BLUE Map Scenario aims to ensure that global energy-related CO_2 emissions are reduced to half their current levels by 2050. This scenario examines ways in which the introduction of existing and new low-carbon technologies might achieve this at least cost, while also bringing energy security benefits in terms of reduced dependence on oil and gas, and health benefits as air pollutant emissions are reduced. The BLUE Map Scenario is consistent with a long-term global rise in temperatures of 2°C to 3°C, but only if the reduction in energy-related CO_2 emissions is combined with deep cuts in other greenhouse-gas emissions. The Baseline Scenario considers the business-as-usual case, not reducing emission levels to any predetermined goal by 2050. The BLUE Map and Baseline Scenarios are based on the same macroeconomic assumptions.

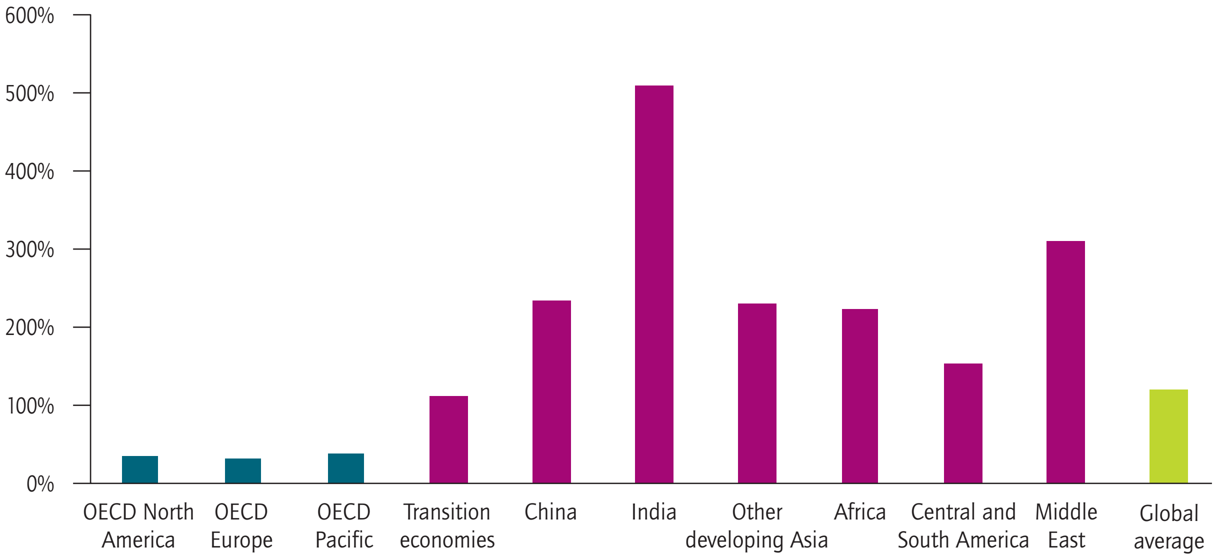
Over the last few decades, generation and network technology deployment, market and regulatory structures, and the volume and use of electricity have changed significantly. This transformation has largely been managed successfully, but ageing infrastructures mean that further changes could affect system stability, reliability and security. Smart grid technologies provide a range of solutions that can be tailored to the specific needs of each region. The primary global system trends and the role of smart grids are illustrated in the following sections using the *Energy Technology Perspectives* (*ETP*) Baseline and BLUE Map Scenarios developed by the IEA to estimate future technology deployment and demand (Box 1).

Future demand and supply

Increased consumption of electricity

Electricity is the fastest-growing component of total global energy demand, with consumption expected to increase by over 150% under the *ETP 2010* Baseline Scenario and over 115% between 2007 and 2050 under the BLUE Map Scenario (IEA, 2010).

Figure 3. Electricity consumption growth 2007-50 (BLUE Map Scenario)



Source: IEA, 2010.

KEY POINT: Emerging economies will need to use smart grids to efficiently meet rapidly growing electricity demand.

Growth in demand is expected to vary between regions as OECD member countries experience much more modest increases than emerging economies and developing countries (Figure 3). In OECD countries, where modest growth rates are based on high levels of current demand, smart grid technologies can provide considerable benefits by reducing transmission and distribution losses, and optimising the use of existing infrastructure. In developing regions with high growth, smart grid technologies can be incorporated in new infrastructure, offering better market-function capabilities and more efficient operation. In all regions, smart grid technologies could increase the efficiency of the supply system and help reduce demand by providing consumers with the information they need to use less energy or use it more efficiently.

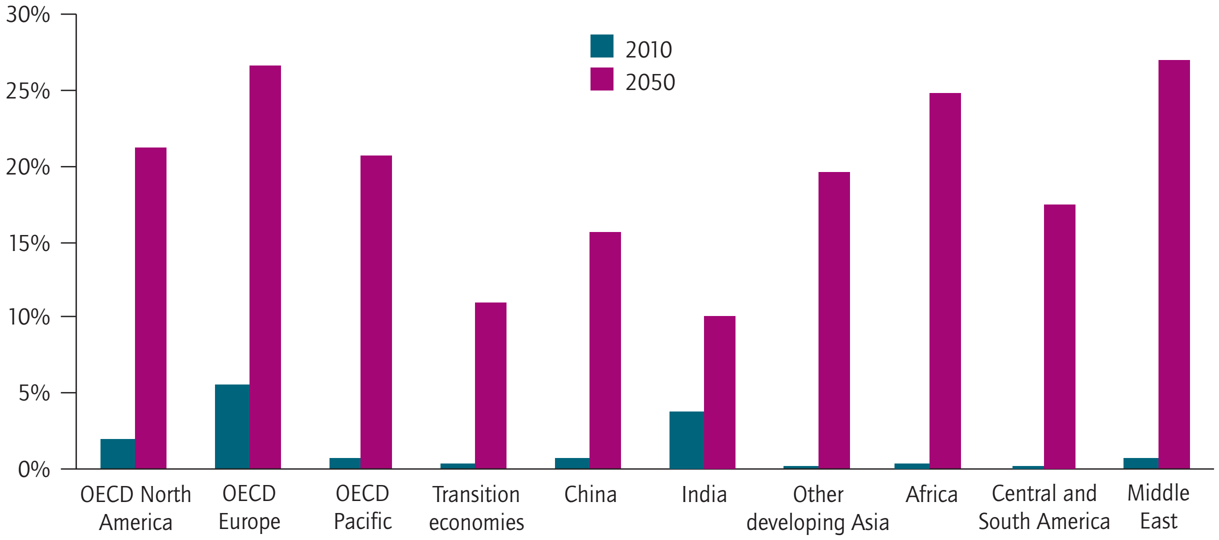
Deployment of variable generation technology

Efforts to reduce CO_2 emissions related to electricity generation, and to reduce fuel imports, have led to a significant increase in the deployment of variable generation technology.[2] This increase is expected to accelerate in the future, with all regions incorporating greater amounts of variable generation into their electricity systems (Figure 4). As penetration rates of variable generation increase over levels of 15% to 20%, and depending on the electricity system in question, it can become increasingly difficult to ensure the reliable and stable management of electricity systems relying solely on conventional grid architectures and limited flexibility. Smart grids will support greater deployment of variable generation technologies by providing operators with real-time system information that enables them to manage generation, demand and power quality, thus increasing system flexibility and maintaining stability and balance.

There are some good examples of successful approaches to integrating variable resources. Ireland's transmission system operator, EirGrid, is deploying smart grid technologies, including high-temperature, low-sag conductors and dynamic

2 Variable generation technologies produce electricity that is dependent on climatic or other conditions, meaning there is no guarantee that it can be dispatched as needed. This includes electricity generation from wind, photovoltaic, run-of-river hydro, combined heat and power, and tidal technologies.

Figure 4. Portion of variable generation of electricity by region (BLUE Map Scenario)



Source: IEA, 2010.

KEY POINT: All regions will need smart grids to enable the effective integration of significantly higher amounts of variable resources to their electricity grids.

line rating special protection schemes, to manage the high proportion of wind energy on its system and maximise infrastructure effectiveness. The operation of the system is being improved through state-of-the-art modelling and decision support tools that provide real-time system stability analysis, wind farm dispatch capability and improved wind forecasting, and contingency analysis. System flexibility and smart grid approaches are estimated to facilitate real-time penetrations of wind up to 75% by 2020 (EirGrid, 2010).

In Spain, Red Eléctrica has established a Control Centre of Renewable Energies (CECRE), a worldwide pioneering initiative to monitor and control these variable renewable energy resources. CECRE allows the maximum amount of production from renewable energy sources, especially wind energy, to be integrated into the power system under secure conditions and is an operation unit integrated into the Power Control Centre. With CECRE, Spain has become the first country worldwide to have a control centre for all wind farms over 10 MW.

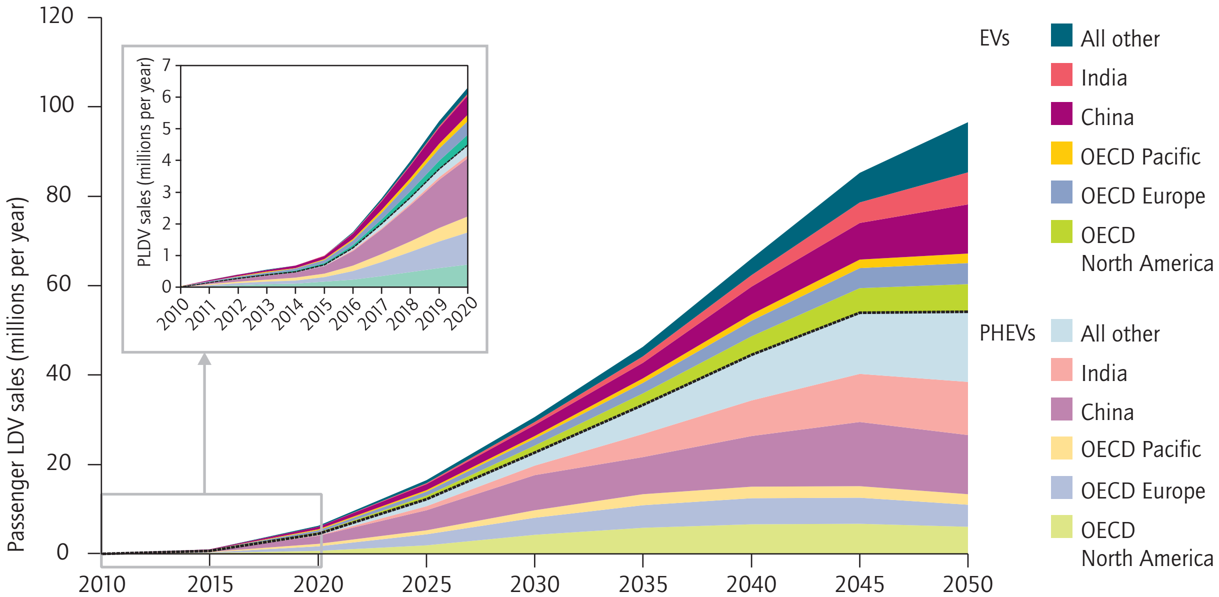
Electrification of transport

The BLUE Map Scenario estimates that the transport sector will make up 10% of overall electricity consumption by 2050 because of a significant increase in electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV) (Figure 5). If vehicle charging is not managed intelligently, it could increase peak loading on the electricity infrastructure, adding to current peak demands found in the residential and service sectors, and requiring major infrastructure investment to avoid supply failure. Smart grid technology can enable charging to be carried out more strategically, when demand is low, making use of both low-cost generation and extra system capacity, or when the production of electricity from renewable sources is high. Over the long term, smart grid technology could also enable electric vehicles to feed electricity stored in their batteries back into the system when needed.[3]

In the Netherlands, the collaborative Mobile Smart Grid project lead by the distribution utility Enexis is establishing a network of electric car recharging sites and is using smart informartion and communication technology (ICT) applications

3 The ownership strategy of the vehicle battery will have a significant impact on whether using vehicle batteries for grid storage is realistic, as this may reduce the life/reliability of vehicle batteries for not much financial return for the vehicle owner. Battery switching technology and leasing models may facilitate the use of vehicle batteries for grid storage.

Figure 5. Deployment of electric vehicles and plug-in hybrid electric vehicles



Source: IEA, 2009.

KEY POINT: Major economies with large personal vehicle sales will need smart grids to enable the effective integration of electric vehicles to their electricity grids.

to enable the existing power network to deal with the additional power demand. Working together with other network operators, energy companies, software and hardware providers, universities and other research institutes, the project should result in simple solutions for charging and paying automatically (Boots *et al.*, 2010).[4]

Electricity system considerations

Ageing infrastructure

The electrification of developed countries has occurred over the last 100 years; continued investment is needed to maintain reliability and quality of power. As demand grows and changes (*e.g.* through deployment of electric vehicles), and distributed generation becomes more widespread, ageing distribution and transmission infrastructure will need to be replaced and updated, and new technologies will need to be deployed. Unfortunately, in many regions, the necessary technology investment is hindered by existing market and regulatory structures, which often have long approval processes and do not capture the benefits of new, innovative technologies. Smart grid technologies provide an opportunity to maximise the use of existing infrastructure through better monitoring and management, while new infrastructure can be more strategically deployed.

Rapidly growing economies like China have different smart grid infrastructure needs from those of OECD countries. China's response to its high growth in demand will give it newer distribution and transmission infrastructure than the other three regions examined in detail in this roadmap (OECD Europe, OECD North America and OECD Pacific). In the Pacific region, recent investments in transmission have resulted in newer infrastructure than that in Europe and North America. OECD Europe has the highest proportion of ageing transmission and distribution lines, but North America has the largest number of lines and the largest number that are ageing – especially at the transmission level. This is an important consideration given the changes in generation and consumption in the IEA scenarios up to 2050, and the need to deploy smart grids strategically. In recent years Japan has invested significantly in its transmission infrastructure, which is operating with very high reliability levels, and is now focusing on its distribution networks. One example is in Yokahama City, where a large-scale energy management project is using both new and existing houses in urban areas to assess the effects of energy consumption on distribution infrastructure.[5] In the United States, as part of a broad range of smart grid investments, significant effort is being devoted to deploying phasor measurement units on the transmission system, providing increased information for more reliable operation of ageing infrastructure.[6]

Peak demand

Demand for electricity varies throughout the day and across seasons (Figure 6). Electricity system infrastructure is designed to meet the highest level of demand, so during non-peak times the system is typically underutilised. Building the system to satisfy occasional peak demand requires investments in capacity that would not be needed if the demand curve were flatter. Smart grids can reduce peak demand by providing information and incentives to consumers to enable them to shift consumption away from periods of peak demand.

Demand response in the electricity system – the mechanism by which end-users (at the industrial, service or residential sector level) alter consumption in response to price or other signals – can both reduce peak demand, but also provide system flexibility, enabling the deployment of variable generation technologies. Reducing peak demand is likely to be the first priority, because demand at a system level is relatively predictable and ramps up and down slowly compared with variable generation. As demand response technology develops and human interactions are better understood, the availability, volume and response time of the demand-side resource will provide the flexibility necessary to respond to both peak demand and variable generation needs.

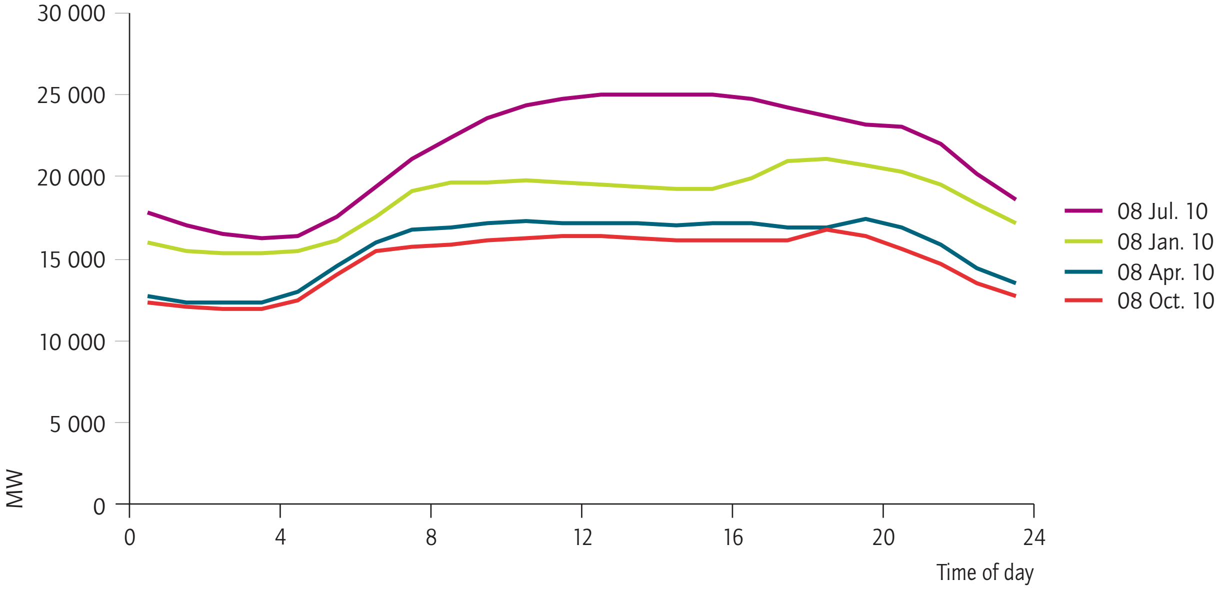
The management of peak demand can enable better system planning throughout the entire electricity system, increasing options for new loads such as electric vehicles, for storage deployment and for generation technologies. These benefits are essential for new systems where demand growth is very high, and for existing and ageing systems that need to maintain existing and integrate new technologies.

4 www.mobilesmartgrid.eu

5 www.meti.go.jp/english/press/data/20100811_01.html

6 www.naspi.org/

Figure 6. Example of a 24-hour electricity system demand curve on several dates over the year



Source: Data from Independent Electricity System Operator, Ontario, Canada.[7]

KEY POINT: The demand for electricity varies throughout the day and across seasons; smart grids can reduce these peaks and optimise system operation.

PowerCentsDC was an advanced meter pilot programme in Washington DC for 850 residential customers that ran over two summers and one winter from July 2008 to October 2009. The programme analysis found that customer response to three different residential pricing options contributed to reducing peak demand, ranging from 4% to 34% in the summer and 2% to 13% in the winter. These results indicate that different price structures enabled by smart grids can reduce peak demand.[8]

Electricity reliability

Growing electricity consumption and recent system failures have focused attention on the role that smart grids can play in increasing electricity reliability – especially by increasing system flexibility. The North American Electric Reliability Corporation (NERC)[9] defines the reliability of the interconnected bulk power system in terms of two basic and functional aspects: adequacy and security.

Adequacy is seen by NERC as the ability of the bulk power system to supply the aggregate electrical demand and energy requirements of its customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements. System operators are expected to take "controlled" actions or procedures to maintain a continual balance between supply and demand within a balancing area. Actions include:

- Public appeals to reduce demand.
- Interruptible demand – customer demand that, in accordance with contractual arrangements, can be interrupted by direct control of the system operator or by action of the customer at the direct request of the system operator.
- Voltage reductions – sometimes as much as 5.
- Rotating blackouts.

Security, in NERC's definition, includes all other system disturbances that result in the unplanned and/or uncontrolled interruption of customer demand, regardless of cause. When these interruptions are contained within a localised area, they are considered unplanned interruptions or

7 www.ieso.ca/imoweb/marketdata/marketSummary.asp

8 www.powercentsdc.org/

9 NERC's mission is to improve the reliability and security of the bulk power system in the United States, Canada and part of Mexico. The organisation aims to do that not only by enforcing compliance with mandatory Reliability Standards, but also by acting as a "force for good" – a catalyst for positive change whose role includes shedding light on system weaknesses, helping industry participants operate and plan to the highest possible level, and communicating Examples of Excellence throughout the industry.

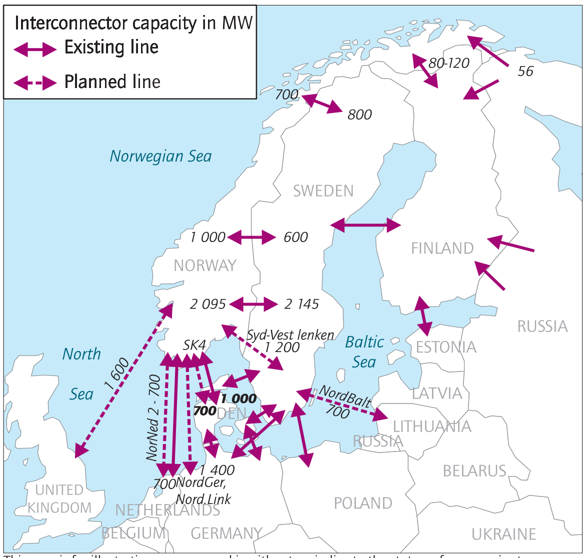
disturbances. When they spread over a wide area of the grid, they are referred to as "cascading blackouts" – the uncontrolled successive loss of system elements triggered by an incident at any location. Cascading results in widespread electric service interruption that cannot be prevented from spreading sequentially beyond an area predetermined by studies.[10]

System adequacy

The considerations for meeting the needs of electricity consumers are significantly different from those for other energy commodities. First, large-scale electricity storage is available only in a few regions that have significant reservoir hydro resources. Second, electricity is traded on a regional rather than on a global basis. It is in this context that electricity production and consumption must be continually monitored and controlled. Smart grid technologies can help to improve system adequacy by enabling more efficient system operation and the addition of regional energy resources to the electricity mix.

The increased amounts of data gathered from a smart grid can show where operational efficiency can be improved and increased automation can improve control of various parts of the system, enabling fast response to changes in demand. The introduction of regional energy resources, including variable generation such as solar, wind, small-scale hydro, and combined heat and power, as well as dispatchable generation such as biomass, reservoir-based hydropower and concentrating solar power systems, will increase the amount of generation capability on the system. Smart grids enable improved, lower-cost integration of these and other variable technologies that may require different electricity system operation protocols.

Figure 7. Transmission links between Nordic countries



This map is for illustrative purposes and is without prejudice to the status of or sovereignty over any territory covered by this map.

Source: Norwegian Ministry of Petroleum and Energy.

KEY POINT: The Nordic electricity system successfully integrates large amounts of variable renewable energy in a regional grid by making use of interconnections.

10 www.nerc.com/page.php?cid=1|15|123

Box 2. Electricity system flexibility

Flexibility is the capability of a power system to maintain reliable supply by modifying production or consumption in the face of rapid and large imbalances, such as unpredictable fluctuations in demand or in variable generation. It is measured in terms of megawatts (MW) available for ramping up and down, over time.

The term flexibility is used here to include power system electricity generation, transport, storage, trading and end-use consumption. Smart grids can optimise the operation of a range of flexibility mechanisms in three contexts: the power market, system operation and the use of grid hardware. Resources that contribute to flexibility include dispatchable power plants, demand-side management and response, energy storage facilities and interconnection with adjacent markets.

Source: IEA,2011.

Adequacy concerns introduced by the deployment of variable generation technology can be addressed by a number of flexibility mechanisms, such as direct trading of electricity between regions. One of the best examples of such trading is the Nordic electricity system, where significant interconnection and well functioning markets between regions allow for high levels of wind energy deployment (Figure 7). Smart grid technology can address the complex power flow problems that result from wide-area wholesale trading by allowing them to be managed with increased efficiency and reliability.

System security

Although a number of OECD countries have recently experienced large-scale blackouts, their electricity systems are regarded as generally secure, according to industry-specific indices that measure the number and duration of outages. Smart grid technologies can maintain and improve system security in the face of challenges such as ageing infrastructure, rising demand, variable generation and electric vehicle deployment. By using sensor technology across the electricity system, smart grids can monitor and anticipate system faults before they happen and take corrective action. If outages do occur, smart grids can reduce the spread of the outages and respond more quickly through automated equipment.

Cyber security

Smart grids can improve electricity system reliability and efficiency, but their use of new ICTs can also introduce vulnerabilities that jeopardise reliability, including the potential for cyber attacks. Cyber security is currently being addressed by several international collaborative organisations. One recent US study summarised the following results (GAO, 2011):

- Aspects of the electricity system regulatory environment may make it difficult to ensure the cyber security of smart grid systems.
- Utilities are focusing on regulatory compliance instead of comprehensive security.
- Consumers are not adequately informed about the benefits, costs and risks associated with smart grid systems.
- Insufficient security features are being built into certain smart grid systems.
- The electricity industry does not have an effective mechanism for sharing information on cyber security.
- The electricity industry does not have metrics for evaluating cyber security.

These findings confirm that cyber security must be considered as part of a larger smart grid deployment strategy. Lessons can be learned from other industries that have addressed these challenges, such as banking, mobile phones and retail, but in the context of infrastructure-related systems, dedicated focus is needed. For example, the Joint Research Council of the European Commission has initiated the European network for the Security of Control and Real-Time Systems (ESCoRTS).[11] ESCoRTS is a joint project among European Union industries, utilities, equipment manufacturers and research institutes, under the lead of the European Committee for Standardisation (Comité européen de normalisation, or CEN), to foster progress towards cyber security of control and communication equipment in Europe. The adoption of such models that work to develop solutions for cyber security, while allowing data to be used for acceptable purposes, is required for successful deployment of smart grid technologies.

11 www.escortsproject.eu/

Smart grid deployment

Smart grid technologies

The many smart grid technology areas – each consisting of sets of individual technologies – span the entire grid, from generation through transmission and distribution to various types of electricity consumers. Some of the technologies are actively being deployed and are considered mature in both their development and application, while others require further development and demonstration. A fully optimised electricity system will deploy all the technology areas in Figure 8. However, not all technology areas need to be installed to increase the "smartness" of the grid.

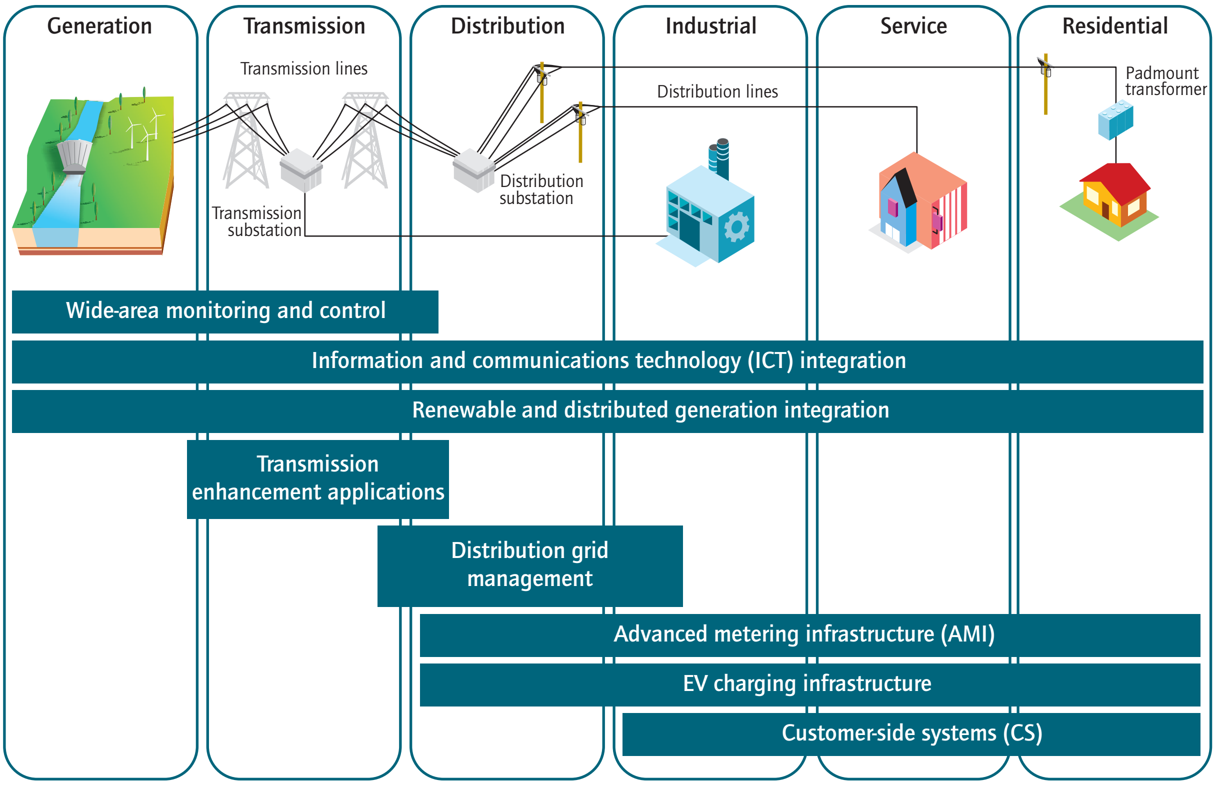
Wide-area monitoring and control

Real-time monitoring and display of power-system components and performance, across interconnections and over large geographic areas, help system operators to understand and optimise power system components, behaviour and performance. Advanced system operation tools avoid blackouts and facilitate the integration of variable renewable energy resources. Monitoring and control technologies along with advanced system analytics – including wide-area situational awareness (WASA), wide-area monitoring systems (WAMS), and wide-area adaptive protection, control and automation (WAAPCA) – generate data to inform decision making, mitigate wide-area disturbances, and improve transmission capacity and reliability.

Information and communications technology integration

Underlying communications infrastructure, whether using private utility communication networks (radio networks, meter mesh networks) or public carriers and networks (Internet, cellular,

Figure 8. Smart grid technology areas



Source: Technology categories and descriptions adapted from NETL, 2010 and NIST, 2010.

KEY POINT: Smart grids encompass a variety of technologies that span the electricity system.

cable or telephone), support data transmission for deferred and real-time operation, and during outages. Along with communication devices, significant computing, system control software and enterprise resource planning software support the two-way exchange of information between stakeholders, and enable more efficient use and management of the grid.

Renewable and distributed generation integration

Integration of renewable and distributed energy resources – encompassing large scale at the transmission level, medium scale at the distribution level and small scale on commercial or residential building – can present chalenges for the dispatchability and controllability of these resources and for operation of the electricity system. Energy storage systems, both electrically and for themally based, can alleviate such problems by decoupling the production and delivery of energy. Smart grids can help through automation of control of generation and demand (in addition to other forms of demand response) to ensure balancing of supply and demand.

Transmission enhancement applications

There are a number of technologies and applications for the transmission system. Flexible AC transmission systems (FACTS) are used to enhance the controllability of transmission networks and maximise power transfer capability. The deployment of this technology on existing lines can improve efficiency and defer the need of additional investment. High voltage DC (HVDC) technologies are used to connect offshore wind and solar farms to large power areas, with decreased system losses and enhanced system controllability, allowing efficient use of energy sources remote from load centres. Dynamic line rating (DLR), which uses sensors to identify the current carrying capability of a section of network in real time, can optimise utilisation of existing transmission assets, without the risk of causing overloads. High-temperature superconductors (HTS) can significantly reduce transmission losses and enable economical fault-current limiting with higher performance, though there is a debate over the market readiness of the technology.

Distribution grid management

Distribution and sub-station sensing and automation can reduce outage and repair time, maintain voltage level and improve asset management. Advanced distribution automation processes real-time information from sensors and meters for fault location, automatic reconfiguration of feeders, voltage and reactive power optimisation, or to control distributed generation. Sensor technologies can enable condition- and performance-based maintenance of network components, optimising equipment performance and hence effective utilisation of assets.

Advanced metering infrastructure

Advanced metering infrastructure (AMI) involves the deployment of a number of technologies – in addition to advanced or smart meters[12] that enable two-way flow of information, providing customers and utilities with data on electricity price and consumption, including the time and amount of electricity consumed. AMI will provide a wide range of functionalities:

- Remote consumer price signals, which can provide time-of-use pricing information.
- Ability to collect, store and report customer energy consumption data for any required time intervals or near real time.
- Improved energy diagnostics from more detailed load profiles.
- Ability to identify location and extent of outages remotely via a metering function that sends a signal when the meter goes out and when power is restored.
- Remote connection and disconnection.
- Losses and theft detection.
- Ability for a retail energy service provider to manage its revenues through more effective cash collection and debt management.

Electric vehicle charging infrastructure

Electric vehicle charging infrastructure handles billing, scheduling and other intelligent features for smart charging (grid-to-vehicle) during low energy demand. In the long run, it is envisioned

12 The European Smart Meters Industry Group (ESMIG) defines four minimum functionalities of a smart meter: remote reading, two-way communication, support for advanced tariff and payment systems, and remote disablement and enablement of supply.

that large charging installation will provide power system ancillary services such as capacity reserve, peak load shaving and vehicle-to-grid regulation. This will include interaction with both AMI and customer-side systems.

Customer-side systems

Customer-side systems, which are used to help manage electricity consumption at the industrial, service and residential levels, include energy management systems, energy storage devices, smart appliances and distributed generation.[13] Energy efficiency gains and peak demand reduction can be accelerated with in-home displays/energy dashboards, smart appliances and local storage. Demand response includes both manual customer response and automated, price-responsive appliances and thermostats that are connected to an energy management system or controlled with a signal from the utility or system operator.

13 Residential small-scale generation equipment on customer premises falls under both categories of consumer-side systems and renewable and distributed energy systems.

Table 3. Smart grid technologies

Technology area	*Hardware*	*Systems and software*
Wide-area monitoring and control	Phasor measurement units (PMU) and other sensor equipment	Supervisory control and data acquisition (SCADA), wide-area monitoring systems (WAMS), wide-area adaptive protection, control and automation (WAAPCA), wide-area situational awareness (WASA)
Information and communication technology integration	Communication equipment (Power line carrier, WIMAX, LTE, RF mesh network, cellular), routers, relays, switches, gateway, computers (servers)	Enterprise resource planning software (ERP), customer information system (CIS)
Renewable and distributed generation integration	Power conditioning equipment for bulk power and grid support, communication and control hardware for generation and enabling storage technology	Energy management system (EMS), distribution management system (DMS), SCADA, geographic Information system (GIS)
Transmission enhancement	Superconductors, FACTS, HVDC	Network stability analysis, automatic recovery systems
Distribution grid management	Automated re-closers, switches and capacitors, remote controlled distributed generation and storage, transformer sensors, wire and cable sensors	Geographic information system (GIS), distribution management system (DMS), outage management system (OMS), workforce management system (WMS)
Advanced metering infrastructure	Smart meter, in-home displays, servers, relays	Meter data management system (MDMS)
Electric vehicle charging infrastructure	Charging infrastructure, batteries, inverters	Energy billing, smart grid-to-vehicle charging (G2V) and discharging vehicle-to-grid (V2G) methodologies
Customer-side systems	Smart appliances, routers, in-home display, building automation systems, thermal accumulators, smart thermostat	Energy dashboards, energy management systems, energy applications for smart phones and tablets

Table 3 highlights a number of hardware and systems and software associated with each technology area.

Within the smart grid technology landscape, a broad range of hardware, software, application and communication technologies are at various levels of maturity. Some technologies have proven themselves over time, but many – even if mature – have yet to be demonstrated or deployed on a large scale. Existing projects give an indication of the maturity levels and development trends of smart grid technologies (Table 4).

Table 4. Maturity levels and development trends of smart grid technologies

Technology area	*Maturity level*	*Development trend*
Wide-area monitoring and control	Developing	Fast
Information and communications technology integration	Mature	Fast
Renewable and distributed generation integration*	Developing	Fast
Transmission enhancement applications**	Mature	Moderate
Distribution management	Developing	Moderate
Advanced metering infrastructure	Mature	Fast
Electric vehicle charging infrastructure	Developing	Fast
Customer-side systems	Developing	Fast

* Battery storage technologies are less mature than other distributed energy technologies.

** High Temperature Superconducting technology is still in the developing stage of maturity.

Smart grid demonstration and deployment efforts

There has been a marked acceleration in the deployment of smart grid pilot and demonstration projects globally, due in part to the recent government stimulus investment initiatives in 2009 and 2010 (Table 5). Investments around the world have enabled hundreds of projects entirely or partly focused on smart grid technologies; the above table provides only a small sample.

Most current smart grid pilot projects focus on network enhancement efforts such as local balancing, demand-side management (through smart meters) and distributed generation. Demonstration projects have so far been undertaken on a restricted scale and have been hindered by limited customer participation and a lack of a credible aggregator business model. Data (and security) challenges are likely to increase as existing pilots expand to larger-scale projects. Non-network solutions such as ICTs are being used in a growing number of smart grid projects, bringing a greater dependence on IT and data management systems to enable network operation (Boots *et al.*, 2010).

The Telegestore project, launched in 2001 by ENEL Distribuzione S.p.A. (*i.e.* prior to the current smart grids stimulus funding) addresses many of these issues. The project installed 33 million smart meters (including system hardware and software architecture) and automated 100 000 distribution substations, while also improving management of the operating workforce and optimising asset management policies and network investments. The project has resulted in fewer service interruptions, and its EUR 2.1 billion investment has led to actual cost savings of more than EUR 500 million per year. ENEL is continually enhancing the system by introducing new features, technologies and flexibility. The project clearly demonstrates the value of a large-scale, integrated deployment of smart grid technologies to solve existing problems and plan for future needs.

Although significant effort and financial resources are already being invested in smart grids, the scale of demonstration and deployment co-ordination needs to be increased. Several organisations have created, are creating or are calling for the creation of an inventory or database of detailed case studies to gather the lessons learned from such projects, particularly in the areas of policy, standards and regulation, finance and business models, technology development, consumer engagement and workforce training.[14]

14 These include the international Smart Grid Action Network, Asia-Pacific Economic co-operation, European Union Set Plan, as well as a number of national initiatives.

Table 5. Select national smart grid demonstration and deployment efforts

Country	National smart grid initiatives
China	The Chinese government has developed a large, long-term stimulus plan to invest in water systems, rural infrastructures and power grids, including a substantial investment in smart grids. Smart grids are seen as a way to reduce energy consumption, increase the efficiency of the electricity network and manage electricity generation from renewable technologies. China's State Grid Corporation outlined plans in 2010 for a pilot smart grid programme that maps out deployment to 2030. Smart grids investments will reach at least USD 96 billion by 2020.
United States	USD 4.5 billion was allocated to grid modernisation under the American Recovery Reinvestment Act of 2009, including: • USD 3.48 billion for the quick integration of proven technologies into existing electric grid infrastructure. • USD 435 million for regional smart grid demonstrations. • USD 185 million for energy storage and demonstrations.
Japan	The Federation of Electric Power Companies of Japan is developing a smart grid that incorporates solar power generation by 2020 with government investment of over USD 100 million. The Japanese government has announced a national smart metering initiative and large utilities have announced smart grid programmes.
South Korea	The Korean government has launched a USD 65 million pilot programme on Jeju Island in partnership with industry. The pilot consists of a fully integrated smart grid system for 6 000 households, wind farms and four distribution lines. Korea has announced plans to implement smart grids nationwide by 2030.
Spain	In 2008, the government mandated distribution companies to replace existing meters with new smart meters; this must be done at no additional cost to the customer. The utility Endesa aims to deploy automated meter management to more than 13 million customers on the low voltage network from 2010 to 2015, building on past efforts by the Italian utility ENEL. The communication protocol used will be open. The utility Iberdrola will replace 10 million meters.
Germany	The government's E-Energy funding programme has several projects focusing on ICTs for the energy system.
Australia	The Australian government announced the AUD 100 million "Smart Grid, Smart City" initiative in 2009 to deliver a commercial-scale smart grid demonstration project. Additional efforts in the area of renewable energy deployments are resulting in further study on smart grids.
United Kingdom	The energy regulator OFGEM has an initiative called the Registered Power Zone that will encourage distributors to develop and implement innovative solutions to connect distributed generators to the network. OFGEM has set up a Low Carbon Networks fund that will allow up to GPB 500m support to distribution network operator projects that test new technology, operating and commercial arrangements.
France	The electricity distribution operator ERDF is deploying 300 000 smart meters in a pilot project based on an advanced communication protocol named Linky. If the pilot is deemed a success, ERDF will replace all of its 35 million meters with Linky smart meters from 2012 to 2016.
Brazil	APTEL, a utility association, has been working with the Brazilian government on narrowband power line carrier trials with a social and educational focus. Several utilities are also managing smart grid pilots, including Ampla, a power distributor in Rio de Janeiro State owned by the Spanish utility Endesa, which has been deploying smart meters and secure networks to reduce losses from illegal connections. AES Eletropaulo, a distributor in São Paulo State, has developed a smart grid business plan using the existing fibre-optic backbone. The utility CEMIG has started a smart grid project based on system architecture developed by the IntelliGrid Consortium, an initiative of the California-based Electric Power Research Institute.

Source: Updated from MEF 2009 using feedback from country experts. Projects are listed in order of largest to smallest amount of investment.

Box 3. Smart communities

Several concepts are emerging that extend the reach of the smart grids from electricity systems to broader energy and societal contexts. One of these is the smart community or smart city. A smart community integrates several energy supply and use systems within a given region in an attempt to optimise operation and allow for maximum integration of renewable energy resources – from large-scale wind farm deployments to micro-scale rooftop photovoltaics and residential energy management systems.

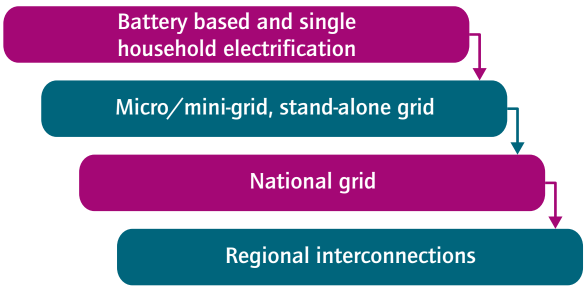
This concept includes existing infrastructure systems, such as electricity, water, transportation, gas, waste and heat, as well as future systems like hydrogen and electric vehicle charging. The goals of such integration through the use of ICT include increased sustainability, security and reliability, as well as societal benefits such as job creation and better services and reduced capital investment. Smart communities are a logical extension of smart grids from electricity systems to other types of infrastructure systems, which are ultimately expected to evolve in this direction.

Tailoring smart grids to developing countries and emerging economies

While advanced countries have well-developed modern grids, many others have grids that do not operate consistently over a 24-hour period, and still others have no electricity infrastructure at all. Developing countries and emerging economies are often categorised by high growth in electricity demand, high commercial and technical losses in a context of rapid economic growth and development, dense urban populations and dispersed rural populations. These aspects present both significant challenges and opportunities. Smart grids can play an important role in the deployment of new electricity infrastructure in developing countries and emerging economies by enabling more efficient operation and lower costs. Small "remote" systems – not connected to a centralised electricity infrastructure and initially employed as a cost-effective approach to rural electrification – could later be connected easily to a national or regional infrastructure.

As a means to access to electricity in sparsely populated areas, smart grids could enable a transition from simple, one-off approaches to electrification (*e.g.* battery- or solar PV-based household electrification) to community grids that can then connect to national and regional grids (Figure 9).

Figure 9. Example of developing country rural electrification pathway



KEY POINT: Developing and emerging economies can use smart grids to build from household electrification to community and regional systems.

The deployment stages in Figure 9 require standardisation and interoperability to be scaled up to the next level with higher amounts of supply and demand. Each successive step can increase reliability and the amount of power available if managed in a way that allows a seamless transition for the community. Roadmaps and targeted analysis focusing on developing countries and emerging economies should assess what lessons can be learned from smart grid demonstrations and deployments in developed countries. Ultimately, the end point of smart grid deployment is expected to be similar across the world, but the routes and time it takes to get there could be quite different (Bazilian, 2011).

Status of electricity system markets and regulation

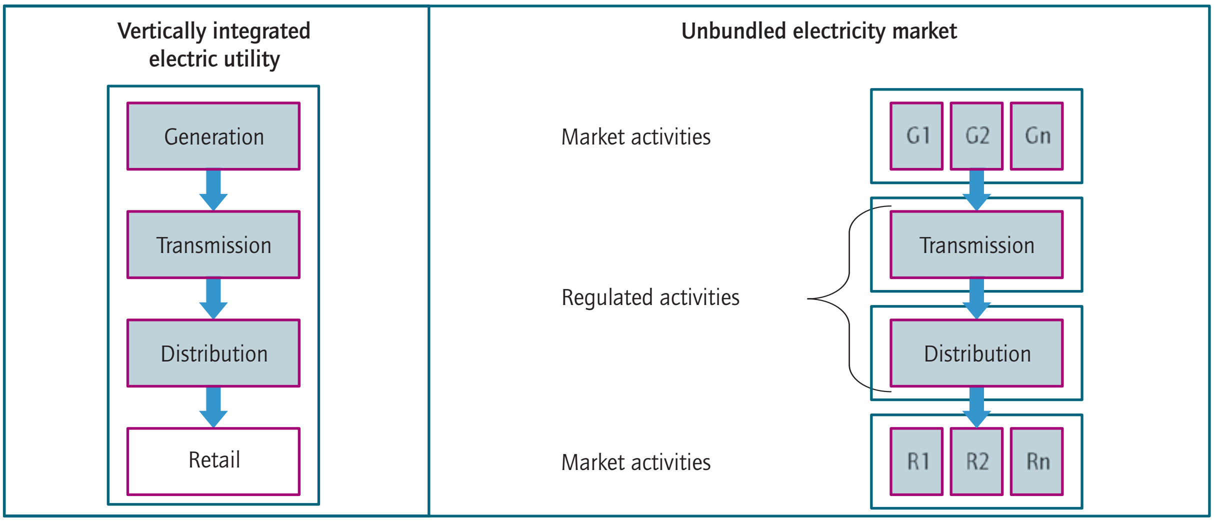
Current regulatory and market systems, both at the retail and wholesale levels, can present obstacles to demonstration and deployment of smart grids. It is vital that regulatory and market models – such as those addressing system investment, prices and customer participation – evolve as technologies offer new options.

Some markets allow vertically integrated utilities, which own and operate infrastructure assets across the generation, distribution and transmission sectors. This ensures that costs and benefits from the deployment of technology are shared and managed efficiently across the various sectors. Vertically integrated structures also allow the most appropriate and fully integrated investment and development for the power system as a whole, rather than just evaluating costs and benefits in one part of the electricity system. It can be difficult for competitors to enter such markets and compete with incumbent players, which could hinder innovation and increase prices for consumers. However, the climate for competitiveness depends largely on whether the market is governed by appropriate regulatory structures.

"Unbundling" of the electricity system, which is intended to allow increased competition, has required entities that operated across the entire system to divide into market-based and regulated units, either functionally by creating separated operating teams within companies or legally by selling companies or creating new ones to separate activities. Market-based activities typically include the generation sector and the retail sector (Figure 10). In the generation sector, markets have developed in which generators sell electricity within a structure defining prices, time frames and other rules. In the retail sector, sometimes the distribution system operator still retails the electricity to consumers and sometimes new participants enter the market that sell only electricity services.

The introduction of market-based activities through unbundling has brought many benefits to the electricity sector, primarily a continued downward pressure on prices, but such objectives can also be met in vertically integrated markets. Varying degrees of unbundling exist around the world. Unbundling also makes it difficult to capture both costs and benefits of various technology deployments on a system-wide basis – especially with respect to smart grids. Smart grid investments are likely to be deployed more rapidly in vertically integrated utilities where the business case can more easily be made. In the many areas where this is not possible, more strategic co-operation between distribution system operators and transmission system operators is needed.

Figure 10. Vertically integrated and unbundled electricity markets



Source: Enexis, 2010.

KEY POINT: The unbundling of electricity markets has introduced benefits and complexity to the electricity sector.

Vision for smart grid deployment to 2050

Smart grids are complex systems that incorporate a number of technologies, consumer interactions and decision points. This complexity makes it difficult to define detailed development and deployment scenarios. Smart grid technologies are being developed worldwide, so much of the research, development and demonstration (RD&D) can be discussed in a global context. But deployment needs to be discussed at the regional level, where important factors such as the age of infrastructure, demand growth, generation make-up, and regulatory and market structures vary significantly.

Regional analysis and impacts for deployment

Motivated by economic, security or environmental factors, countries will choose their own priorities when adopting smart grid technologies. Where possible, the costs and benefits of different approaches must be quantified to assess the impacts of potential smart grid deployment. The following regional characteristics need to be taken into account in any regional assessment:

- Current and planned mix of supply, including fossil, nuclear and renewable generation.
- Current and future demand, and sectoral make-up of demand, such as manufacturing industry, residential load prevalence or the deployment of electric vehicles.
- Status of existing and planned new transmission and distribution networks.
- Ability to interconnect with neighbouring regions.
- Regulatory and market structure.
- Climatic conditions and resource availability.

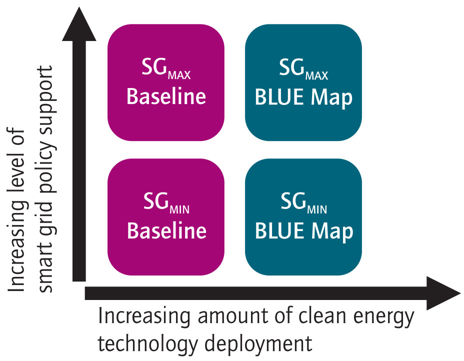
Quantification of peak demand and the impact of smart grids[15]

The incentives, or drivers, behind smart grid deployment and the interactions between such drivers need to be understood in the context of local or regional electrical systems. This roadmap has expanded upon the *ETP 2010* scenarios to develop a more detailed regional electricity system vision for four regions: OECD North America, OECD Europe, OECD Pacific and China. Data in the analysis includes:[16]

- Annual demand.
- Electric vehicle (EV) deployment and peak demand as a function of EV deployment.
- Demand response potential.
- Future potential electricity use in buildings.
- Deployment of advanced metering infrastructure.

The model focuses on the demand side of the electricity system; variable renewable deployment is considered in the discussion but not in the analysis itself.[17] The scenarios modelled are shown in Figure 11. In the SG_{MAX} scenario, there is strong regulatory and policy support for the development and deployment of smart grids, whereas the SG_{MIN} scenario assumes little policy support. The amount of clean technology installed – such as heat pumps, variable renewable resources (varRE) and electric vehicles (EVs/PHEVs) – follows the deployment pathways developed by the *ETP 2010* analysis in the Baseline and BLUE Map Scenarios.

Figure 11. Regional smart grids analysis structure



KEY POINT: Two scenarios – SG_{MAX} and SG_{MIN} – were conducted to assess smart grids impact on peaking demand under the ETP Baseline and BLUE Map Scenarios.

15 A detailed description has been developed as an IEA working paper. entitled: *Impact of smart grid technologies on peak load to 2050.*

16 Energy efficiency improvements in end-use sectors are modelled in the ETP BLUE Map and Baseline Scenarios.

17 Although smart grids will play a role in all parts of system operation, this roadmap will examine the impact of smart grids on peak demand. By focusing on the demand portion of the electricity system, this analysis is complementary and related to the IEA GIVAR study, which focuses on electricity system flexibility in terms of variable renewable generation deployment. Both sets of analysis will be integrated at a later time.

Since smart grids are already being deployed, policy support is assumed to be at least at a minimum level; a scenario without smart grids will be shown only as reference case to demonstrate that where EVs/PHEVs are deployed with no consideration for electricity system operation, they can have a significant negative impact on peak demand. The key variables used, in addition to *ETP 2010* analysis values, are the reduction of peak demand through demand response and electric vehicle connections: grid-to-vehicle (G2V), or battery charging, and vehicle-to-grid (V2G), in which electricity flows from batteries into the grid.

Table 6. Modelling scenarios for SG_{MIN} and SG_{MAX}

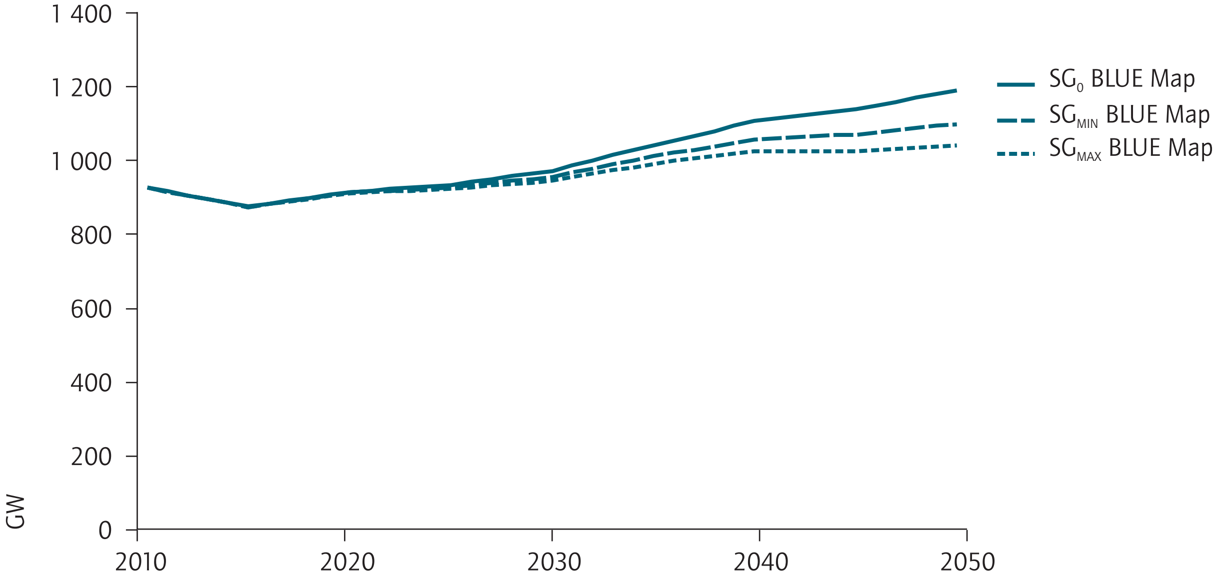
SG_{MIN}	SG_{MAX}
Demand response low (5)	Demand response high (15)
G2V scheduled	G2V scheduled and V2G deployed

Note: Values for demand response were chosen from Faruqui, 2007; it should be noted that further demand response technological developments could significantly increase these amounts.

Impact of electric vehicles on peak demand

The deployment of EV/PHEV technology can have a significant positive or negative impact on peak demand. The demand cycle for EV/PHEV charging could be similar to the daily demand cycles of residential and service sector consumers – adding to existing peak demand. If charging is performed in a controlled fashion, simply through a scheduling process, or interactively with signals from utilities, the impact on peak demand could be significantly minimised. The electricity storage in EVs/PHEVs could also be used to reduce the impact of peak demand by providing electricity at or near end-user demand (V2G). Figure 12 shows both the positive and negative impact of EVs/PHEVs on peak demand for OECD North America with no demand response capability installed. The trend is similar in all regions.

Figure 12. OECD North America EV deployment impact on peak demand



KEY POINT: Smart grid deployment can reduce the peak electricity demand associated with the charging of electric vehicles and contribute to reducing overall peak demand by enabling V2G.

Figure 12 shows the SG_0 case with total peak demand under the BLUE Map Scenario with no demand response capability and deployment of EVs/PHEVs to 2050. In this case, peak demand increases faster than overall consumption – 29% over the 2010 value by 2050. When some level of scheduling spreads out the charging of EVs/PHEVs over the course of the day, the increase in peak demand is reduced to 19% over the 2010 value. When both scheduled charging and V2G are deployed, peak demand increases by only 12% by 2050. With the addition of demand response, peak demand could be held steady at 2010 values.

Regional scenarios for deployment to 2050

This roadmap compares the impact of smart grids on system operation among four regions, combining the ETP BLUE Map Scenario with the SG_{MAX} and SG_{MIN} scenarios. In the SG_{MIN} BLUE Map Scenario, deployments of clean energy technology such as VarRE and EVs/PHEVs are significant, but policy support for smart grids is modest. In the SG_{MAX} BLUE Map Scenario, deployments of clean energy technology such as varRE and EVs/PHEVs are the same as in the SG_{MIN} case, but the policy support for smart grids is strong. Tables 7 and 8 look at the increase in peak demand and overall electricity demand compared with 2010 values for the different regions.

Table 7 shows that China will see more growth in electricity demand than the other regions will see in 40 years on a net and percentage basis. The other regions will only see growth in the range of 22% to 32% from 2010 to 2050, and no net growth in the near future because of low economic growth and the deployment of energy efficiency technologies. Some minor reductions in transmission and distribution line losses have been included in the analysis, but they have little impact on overall demand.

Table 7. Increase in electricity demand over 2010 values for SG_{MIN} and SG_{MAX} scenarios* (%)

	2020	2030	2040	2050
China	53	90	122	170
European Union	0	10	26	27
North America	-3	1	16	22
Pacific	0	6	17	32

* Electricity generation was modeled using the same parameters for both the SG_{MIN} and SG_{MAX} scenarios.

Table 8 shows that in all cases, the SG_{MAX} scenario sees a significant decrease in peak demand, providing the opportunity to delay investments in and/or reduce stress on existing infrastructure, especially in the context of new loads such as EVs/PHEVs. The most interesting case is North America, where a 22% increase in overall electricity demand can be seen, but only a 1% increase in peak demand by 2050 in the SG_{MAX} case. China's overall demand growth has a dramatic effect on the country's peak demand over 2010 levels and is the dominant driver for this increase in the analysis. In other regions, peak demand is increased by deployment of EVs/PHEVs and greater use of electricity in buildings. All regions except China show that the deployment of smart grids, even to a minimum level, can decrease the rate of peak load demand to a level below overall demand growth.

Table 8. Increase in peak demand over 2010 values for SG_{MIN} and SG_{MAX} scenarios (%)

		2020	2030	2040	2050
China	SG_{MIN}	56	99	140	200
	SG_{MAX}	55	91	125	176
European Union	SG_{MIN}	1	13	30	32
	SG_{MAX}	-4	5	18	17
North America	SG_{MIN}	-4	0	10	15
	SG_{MAX}	-10	-9	0	1
Pacific	SG_{MIN}	-2	4	12	25
	SG_{MAX}	-7	-4	2	11

Interpreting results and further analysis

The regional results provide guidance for the types of pathways that each region might follow as they develop smart grids. China has the opportunity to deploy smart grid technologies to better plan and design the new infrastructure that is being built, thereby reducing the negative impacts on peak demand from the deployment of EVs/PHEVs. OECD Europe and OECD Pacific[18] demonstrate similar trends with respect to all drivers, but OECD Europe shows the highest peak demand of the OECD regions considered. OECD Europe also must manage deployment within an older infrastructure base and with higher deployments of variable generation technology. OECD North America can benefit significantly from the deployment of smart grids, given that it is the largest electricity market in the world and has an ageing infrastructure, especially at the transmission level. A North American smart grid pathway might therefore focus on the benefits of demand response and transmission system monitoring and management.

This roadmap provides some insights into the benefits and possible regional pathways for smart grids deployment, but more analysis is needed, particularly of the generation side, to provide a more complete picture of system performance. Additional regional examination is also needed to consider specific system attributes. Major characteristics of developing countries were not considered in this modelling, and should be added to provide insights into developing regions.

Smart grid CO_2 emissions reduction estimates to 2050

Although electricity consumption only represents 17% of final energy use today, it leads to 40% of global CO_2 emissions, largely because almost 70% of electricity is produced from fossil fuels (IEA, 2010). In the ETP BLUE Map Scenario, as a result of decarbonisation, electricity generation contributes only 21% of global CO_2 emissions, representing an annual reduction of over 20 Gt of CO_2 by 2050. Smart grid technologies will be needed to enable these emissions reductions. Direct reductions will occur through feedback on energy usage, lower line losses, accelerated deployment of energy efficiency programmes, continuous commissioning of service sector load, and energy savings due to peak load management. Indirect benefits arise from smart grid support for the wider introduction of electric vehicles and variable renewable generation.

Taking these direct and indirect emissions reductions into account, the ETP BLUE Map Scenario estimates that smart grids offer the potential to achieve net annual emissions reductions of 0.7 Gt to 2.1 Gt of CO_2 by 2050 (Figure 13).[19] North America shows the highest potential for CO_2 emissions reduction in the OECD, while China has highest potential among non-OECD member countries.

Estimating smart grid investment costs and operating savings

A high-level cost/benefit analysis is vital for the deployment of smart grids. Work carried out so far in the roadmap process is providing the foundation for such an analysis, but more effort is needed as additional data and modelling become available. The cost discussion needs to include the three main electricity stakeholders: utilities, consumers and society.

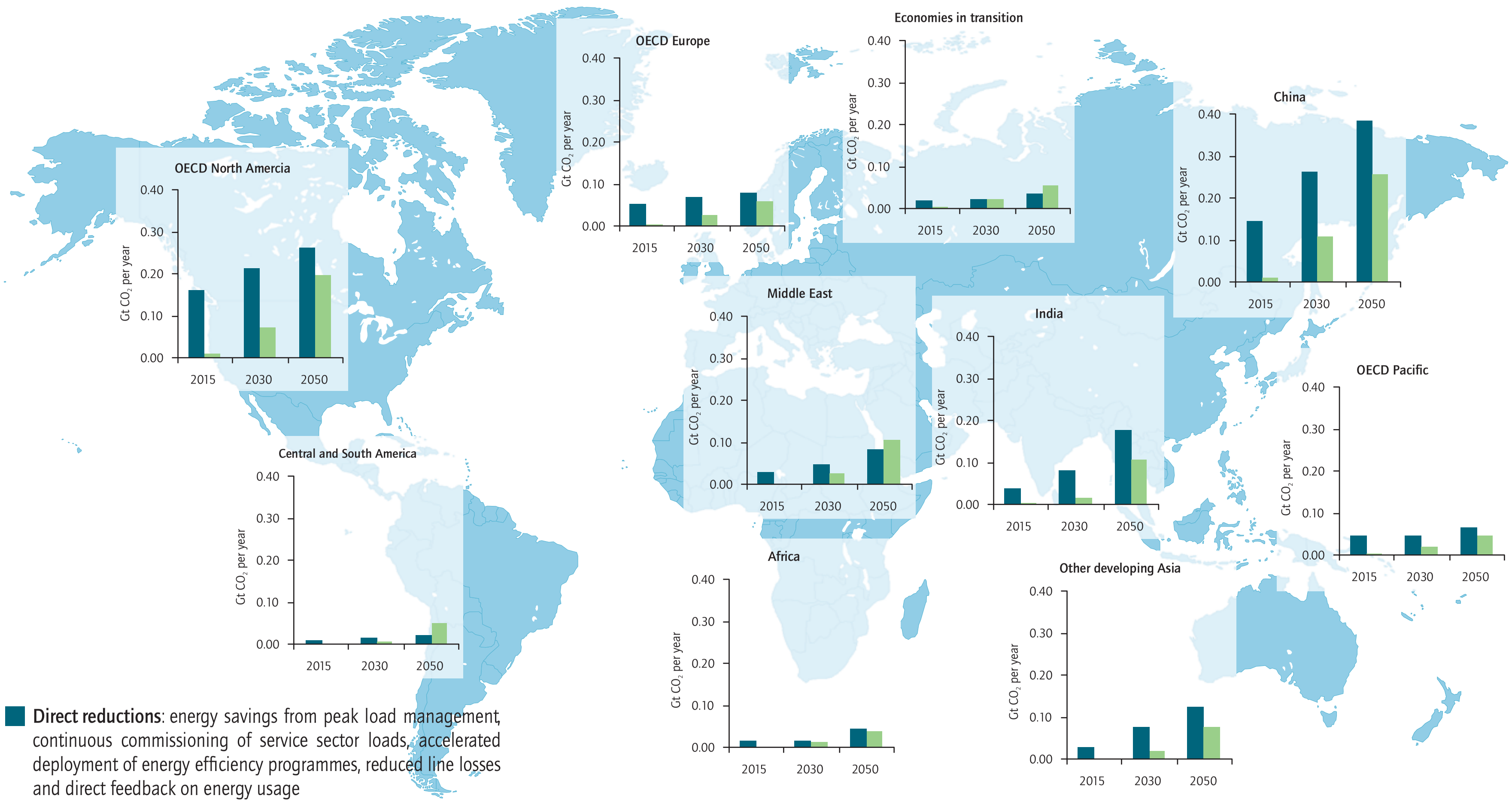
Utilities will experience both costs and savings in the deployment of smart grids, in the areas of operating and capital expenditure. The deployment of new generation (such as variable generation) and end-use technologies (such as electric vehicles) could increase the need for investment in infrastructure, therefore raising capital expenditures; but smart grids have the potential to reduce peak demand, better manage generation from both variable and dispatchable sources, and therefore reduce the potential increases in conventional infrastructure costs. Operating savings can come from decreased costs for maintenance, metering and billing, and fuel savings through increased efficiencies and other areas.

Electricity production costs fluctuate according to basic supply and demand conditions in the market, generation variability (such as unplanned outages), system congestion and the prices of

18 Although OECD Pacific is modelled as a single region, its countries are not highly interconnected; further analysis must be carried out to determine how this will affect the areas of concern demonstrated in the model.

19 The methodology for calculating the emissions reduction benefits requires further refinement but this provides an indication of the potential reductions.

Figure 13. Regional CO_2 emissions reduction from smart grid deployment



■ **Direct reductions**: energy savings from peak load management, continuous commissioning of service sector loads, accelerated deployment of energy efficiency programmes, reduced line losses and direct feedback on energy usage

■ **Enabled reductions**: greater integration of renewables and facilitation of EV and PHEV deployment

KEY POINT: Smart grid deployment enables significant CO_2 emissions reductions.

commodities such as oil, gas, coal and nuclear fuel. In markets where consumers are billed using pricing schemes that do not vary based on real production costs (flat-rate based pricing), there is no real- or near real-time link to production costs and consumption. Smart grids can help **consumers** manage energy use – by taking advantage of lower off-peak prices, for example – so that even if the price of electricity is significantly higher during peak times, their monthly or annual bills would change little. Technology that can accomplish this varies in industrial, service and consumer sectors; some of it is mature and has been deployed for many years, especially in the industrial sectors. Further study is required of the costs and benefits and behavioural aspects of electricity usage in order to identify solutions that enable consumers to manage electricity better and minimise costs.

The environmental costs and security benefits to **society** of the electricity system are not completely taken into account in current regulatory frameworks for production, use and market arrangements. Companies typically invest large amounts of capital to build electricity system assets and receive regulated rates of return over a long time period – especially in the transmission and distribution sectors. In the current technologically mature market, this is a low-risk, low-reward model. Future grid regulation, however, will need to incorporate factors such as greenhouse gas emission reductions and system security into operating costs. For smart grid deployment to become a reality, all stakeholders must bear their fair share of benefits, costs and risks – especially end-users, who ultimately pay for the electricity service. This can only happen through clever market design and regulation, and sustained stakeholder engagement that will enable new technology demonstration or deployment at an acceptable level of risk, taking into account the existing status of the system as well as future needs. If this is accomplished, the costs and benefits can be rationalised and defended, ensuring the development of a clean, secure and economical electricity system.

Technology development: actions and milestones

This roadmap recommends the following actions:	Milestones
Build up commercial-scale demonstrations that operate across system boundaries of generation, transmission, distribution and end-use and that incorporate appropriate business models addressing key issues including cost, security and sustainability.	Concentrated effort from 2011 to 2025
Enable increased levels of demand response for customers from industrial, service and residential sectors, co-ordinating collaboration and responsibilities among electricity system stakeholders.	Completed by 2020
Develop and demonstrate consumer-based enabling technologies including behavioural, policy and technical aspects.	2011 to 2020

Development and demonstration

The need for commercial-scale demonstration

The existing smart grid technology landscape is highly diverse. Some technology areas exhibit high levels of maturity while others are still developing and not ready for deployment. Although continued investments in research and development are needed, it is even more important to increase investments in demonstration projects that capture real-world data, integrated with regulatory and business model structures, and to work across segmented system boundaries – especially interacting with end-use customers. While this is happening currently as a result of stimulus funding (Table 5), it is vital that it continue to expand. Only through large-scale demonstrations – allowing for shared learning, reduction of risks and dissemination of best practices – can the deployment of smart grids be accelerated. Current levels of political ambition appear to be sufficient, but high quality analysis and positive demonstration outcomes must be highlighted to sustain these levels.

Demand response enabled by smart grids

Demand response (DR) is one of the key approaches enabled by smart grids. Changes in the generation sector will include the increased deployment of variable generation to levels over 20% of overall demand in many regions, with some regions significantly surpassing this level. Increased consumption of electricity from both existing and new loads will continue to place stress on the electricity system and increase peak demand. Variable generation resources and peak demand can be managed by a range of mechanisms – DR being one – where more potential is ready to be exploited.

Load management, in the form of direct load control, peak shaving, peak shifting and various voluntary load-management programmes, has been implemented since the early 1980s. With demand response, the system operator will be able to monitor and manage demand; the electricity grid will thus move from load-following to load-shaping strategies in which demand-side resources are managed to meet the available generation and the grid's power delivery capabilities at any given time (Ipakchi and Albuyeh, 2009).

Demand response cuts across several technology areas highlighted earlier, including customer-side systems, advanced metering infrastructure, distribution management and automation, and sometimes stretching from generation to end-use. Additionally, there are three main customer groups with different DR profiles: industrial, service and residential. A relatively few industrial customers with large electricity demands could have a significant impact on the electricity system; mature technologies and market approaches exist for applications in this end-use sector. A large number of residential consumers would be needed to have a similar effect and the technology, behavioural and market models are much less mature. The service sector falls somewhere in the middle.

Demand response can significantly reduce peak demand and – in the longer term – provide the flexibility needed, both in volumetric terms and in speed of response, to support variable generation technologies. Given current technological and market design maturity levels, however, system operators have made it clear that more work is needed in the near term to understand the key factors that will enable DR in the residential and service sectors. In addition to system operators, generation stakeholders who depend on system flexibility, such as wind and solar farm operators, must actively support DR technology development and demonstration as a way to increase flexibility and ensure increasing deployment levels into the grid can be managed effectively. Other DR stakeholders, including aggregators, technology developers and industrial, service and residential customers, must also collaborate to ensure that technology development meets all parties' needs with due consideration of regulatory and market mechanisms.

Development of consumer-based enabling technologies

Pilot projects have shown that certain so-called enabling technologies enhance the ability of smart grids consumers to adjust their consumption and save on their electricity bills. These enabling technologies also improve the sustainability of end-user behaviour change over time. Considerable innovation is under way in this field and numerous enabling technologies have already been developed and piloted, including in-premise customer displays or "energy dashboards", programmable and price-responsive end-use controllers, and home or facility-wide automation networks.

Some research projects are looking into the behavioural aspects of presenting feedback on consumption, as well as opportunities for automated end-use load control. As with many emerging fields, the range of approaches is wide and early results vary considerably.

Key enabling technology development questions include:

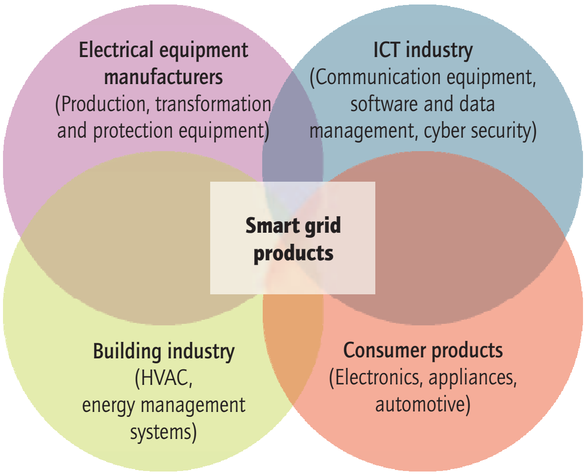
- Is there an optimal mix of behavioural modification and automation technologies?
- How much customer education is required and what are the best approaches?
- What policies can governments adopt to encourage innovation without picking technology winners?
- What is the impact of ICT choices (*e.g.* private/ dedicated carriers vs. public-based carriers such as the Internet) on enabling technology development?

Standards

This roadmap recommends the following actions:	***Milestones***
Governments and industry should evaluate priorities and establish protocols, definitions and standards for equipment, data transport, interoperability and cyber security, and create plan for standards development to 2050.	From 2011 to 2013
Expand collaboration in the development of international standards to reduce costs and accelerate innovation while developing globally accepted standards.	Continue from 2011 to 2050

Smart grid equipment and systems are provided by many industry sectors that historically have not worked together, such as equipment manufacturers, ICT providers, the building industry, consumer products and service suppliers. Control systems operated by utilities whose networks interconnect need to be able to exchange information. Customer-owned smart appliances, energy management systems and electric vehicles need to communicate with the smart grid. Standards, definitions and protocols for transport of data are essential for this complex "system of systems" to operate seamlessly and securely (Figure 14).

Figure 14. Smart grid product providers



Source: Canmet Energy/Natural Resources Canada (not previously published)

KEY POINT: A broad range of product and service providers who have not worked together in the past will have to collaborate in smart grids deployment.

International perspective on standards

Variations in equipment and systems to meet differing national standards add cost; this eventually gets passed on to consumers. International standards are needed to promote supplier competition and expand the range of options available to utilities, resulting ultimately in lower costs for consumers. Connection of national electric grids with those of adjacent countries – as in the Americas and in Europe, for example – will also be facilitated by expanded international standards. For all these reasons, it is in the interest of countries developing smart grids to collaborate on international standards.

Smart grids will eventually require hundreds of standards to be completely specified. Some of the highest priority areas include:[20]

- Advanced metering infrastructure (AMI).
- Interfaces between the grid and the customer domain to support demand response and energy efficiency applications.
- Phasor measurement units and other sensors that increase wide-area situational awareness.
- Distribution grid automation and integration of renewable resources.
- Interconnection of energy storage.
- Communication with electric vehicles to manage charging.
- Data communication in the smart grid.
- Cyber security.

Benefits of interoperability

Interoperability refers to the ability of two or more networks, systems, devices, applications or components to communicate and operate together effectively, securely, and without significant user intervention. The evolution of telecommunication networks and the Internet over the last 40 years has demonstrated the benefits of having robust interoperability standards for large infrastructure systems. Standards prevent premature obsolescence, facilitate future upgrades and ensure systems can be scaled up for larger deployments. Standards can also provide for backward compatibility, integrating new investmentswith existing systems. Standards are needed to support the development of mass markets for smart appliances and electric vehicles that can communicate with the grid regardless of location or service provider. The introduction of information technologies in the smart grid introduces new cyber vulnerabilities that must be protected against by the rigorous application of cyber security standards. Standards will also protect privacy while enabling customers to securely access information on their own energy consumption.

Highlights of ongoing activities

At the international level, technical standards underpinning the smart grid are being developed by several organisations.[21] Since the standards all need to work together to support an overall system, co-ordination of efforts by these organisations is critically important.

In the United States, the National Institute of Standards and Technology (NIST) has been leading a major co-ordination programme, which has developed and published the Release 1.0

20 Adapted from NIST, 2010.

21 Including International Electrotechnical Commission (IEC), International Institute of Electrical and Electronics Engineers (IEEE), International Organization for Standardization (ISO), International Telecommunications Union Standardization Sector (ITU-T), and many other.

Interoperability Framework for smart grids. NIST has co-operated with many other countries that are working on smart grids to share work and facilitate collaboration, and has also established a new independent organisation, the Smart Grid Interoperability Panel. Nearly 600 companies and organisations from around the world are participating in the panel, which is co-ordinating the work of over 20 standards development organisations, including those listed above.

In Europe, a European Joint Working Group for Standardisation of Smart Grids has recently been established in which CEN, CENELEC, ETSI[22] and the European Commission are participating. Japan has developed an initial standards roadmap for smart grids and has also formed a Smart Community Alliance, which has extended the concept of smart grids beyond the electric system to encompass energy efficiency and efficient management of other resources, such as water, gas and transportation. The government of Korea has announced a plan to build a national smart grid network and is beginning work on a standards roadmap. In China, the State Grid Corporation has developed a draft Framework and Roadmap for Strong and Smart Grid Standards.

The major economies are all contributing to the development of international standards upon which national standards can be based. Continued communication and collaboration will create excellent prospects for international harmonisation of many smart grid standards, especially those dealing with the new information aspects of the grid, while taking into account the diversity of infrastructure requirements around the world.

22 European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC), European Telecommunications Standards Institute (ETSI).

Policy and regulatory framework: actions and milestones

Collaborating on a policy and regulatory environment that supports smart grid investment is perhaps the single most important task for all stakeholders in the electricity sector.[23] A lack of collaboration has already led to problems in demonstration and deployment projects. As with most policy issues, the key is to find the right balance in sharing costs, benefits and risks. The responsibility for achieving this balance lies with regulators and, in some cases, legislators, but must include input from all stakeholders. Key policy questions that regulators must answer include:

- How should smart grid investment costs be recovered? If shortfalls in benefits occur, how should they be shared between utilities and consumers?
- How can additional services (such as balancing, demand response, energy retailing) be enabled by new regulations and smart grid technologies?
- Should electricity rate options be compulsory or voluntary?
- Should vulnerable customers be protected from the possibility of higher bills? If so, how?
- Should advanced technology investments such as smart grids, which carry the extra risk of technology obsolescence, be treated differently from other utility investments?
- Should some customer groups less able to participate in dynamic pricing be excused from bearing the extra costs of smart grids or being subject to new service conditions? If so, what can or should be done for these customers?
- What is the impact of differing tariff structures between interconnected regions?

23 Many other issues associated with smart grid deployments need to be addressed such as: providing for utility cost recovery; encouraging volumetric decoupling; providing metering compatibility; implementing demand response; and moving towards wholesale market integration. Although not directly related to smart grid deployment, well-developed policies in these areas can help accelerate the beneficial impacts of smart grids.

Generation, transmission and distribution

This roadmap recommends the following actions:	***Milestones***
Cross-sector	
Determine approaches to address system-wide and cross-sector barriers to enable practical sharing of smart grids costs and benefits.	Completed by 2020
Address cyber security issues proactively through both regulation and application of best practice.	Ongoing to 2050
Generation	
Develop an evolutionary approach to regulation for changing the generation landscape from existing and conventional assets to more variable and distributed approaches – including both large and small electricity generation.	2011 to 2030
Develop regulatory mechanisms that encourage business models and markets to enable a wider range of flexibility mechanisms in the electricity system to support increased variable generation penetration.	2011 to 2030
Transmission	
Continue to deploy smart grids on the transmission system to increase visibility of operation parameters and reliability.	Ongoing
Assess the status of regional transmission systems and consequently future requirements in smart grid technology applications to address existing problems and potentially delay near- and medium-term investments.	Continued 2011 to 2020
Distribution	
Determine policy approaches that can use smart grids to leverage distribution system investments strategically and optimise benefits.	2011 to 2020
Promote adoption of real-time energy usage information and pricing that will allow for optimum planning, design and operation of distribution system in co-operation with customers.	Focused effort from 2011 to 2020, ongoing to 2050

Electricity system and market operation can benefit from the deployment of smart grids, but regulatory changes are required to ensure that all stakeholders – especially consumers – share the costs and the benefits. Many of these issues have not yet been examined in detail yet, so as well as offering solutions to certain issues, this section will indicate where more work is needed.

Cross-sector considerations

Unbundling and liberalisation of the electricity system has increased the institutional and market complexity associated with system planning, operations and services. Functional unbundling and new operating entities have complicated ownership and operations, which are often under different or dual regulatory jurisdictions, and have added uncertainty as regards delivering needed investment. Under these conditions, there are increased barriers to the demonstration and deployment of smart grids, and an increased need to address these across all sectors, rather than only at the sectoral level. Smart grids costs and benefits can be more easily shared if they are considered across all sectors.

As discussed earlier, cyber security is a key issue as the deployment of increased ITCs introduces new vulnerabilities to the system. These must be proactively addressed across all sectors of the electricity system as opposed to simply meeting regulatory requirements. This will require increased effort for regulators, system operators and technology providers.

Electricity generation sector

The deployment of variable generation is expected to increase to over 20% of overall supply in many regions (with some regions significantly surpassing this level), supported by government policy and regulation, at state, provincial and regional levels. Regulatory mechanisms need to be developed to encourage business models and markets that enable sufficient flexibility required by variable generation deployment to ensure reliable system operation. Markets must be transparent to allow asset owners and third parties to enter and offer conventional as well as innovative solutions to provide such flexibility. More effort is needed in demonstrating and verifying the interactions between well-known and established approaches (such as peaking generation plants) and other flexible approaches (including expanded DR applications), along with market design refinements that enable continued innovation.

A new factor in recent years in the electricity generation sector is the rise in the number of electricity consumers who produce small amounts of electricity at or near the place of consumption – often referred to as "prosumers". Management of this sort of distributed generation can be better enabled by smart grids, through increased information, and creation of beneficial market and regulatory structures. Many policies and regulations have been established globally to support this type of generation, such as feed-in tariffs and accompanying grid interconnection policy. But this will need continuing evaluation to ensure the maximum amount of customer-sited generation at lowest cost can be deployed, with consideration to all electricity system stakeholders.

The deployment of smart grids may have a negative impact on some types of generation. As global electricity demand increases, smart grids may slow demand growth by enabling more efficient system operation but are not likely to significantly decrease the use of existing assets to meet power needs. On a regional basis, certain assets may become redundant as smart grids are deployed, because of decreased electricity demand, shifting demand profiles and new approaches to increase system flexibility or provide ancillary services. As smart grids will enable increased DR and electricity storage that reduces the need for peaking generation, identification of possibly redundant assets should be carried out at the earliest possible point in smart grid deployment to allow for appropriate planning and cost/benefit analysis. Regulatory treatment of such stranded assets is well developed, however, and existing regulatory structures can be used to facilitate loss recovery.

Transmission networks

Investment in the smartening of transmission networks is occurring around the world. Many transmission systems already use some smart grid technologies and are operating robustly, allowing for adequate competition among generators and therefore ensuring appropriate electricity prices. Other transmission systems are plagued by congestion and concerns over ageing infrastructure.

Even as transmission systems are being smartened, new transmission capacity and interconnections with other electricity systems are also needed. Deploying new transmission is often complicated by the unbundled and liberalised nature of electricity systems and by lengthy approval processes. Some countries now investing in national-scale transmission systems (*e.g.* China), are not experiencing these issues and have been able to deploy modern transmission systems very quickly, defining smart grids as "strong and smart grids" and making use of modern HVDC technologies.

Other countries could benefit from greater regional assessment of the current status and future requirements of transmission systems, to identify technology applications and requirements for additional capacity and interconnection. Such assessments can lead to new technical and regulatory solutions that optimise the operation and planning of existing systems, enabling the deferment of conventional investments that may be hindered by long approval processes or local opposition. To enable efficient operation today as well as accommodate future changes, government and regulatory policies must allow timely and adequate transmission system investment; inadequate investment brings risks of higher costs in the future and of system failures.

Distribution networks

The smartening of distribution networks can bring significant benefits to operators and customers, but requires considerably more effort than smartening transmission networks. Distribution networks have many more nodes to be instrumented and managed, and ICT requirements are much higher. Distribution systems connect to nearly all electricity customers (excluding large industrial customers connected to the transmission system), as well as distributed generation, variable/dispatchable resources and new loads such as electric vehicles. Smart grid technology must be strategically deployed in order to manage this complexity, as well as the associated costs, to the benefit of all stakeholders.

Market unbundling has changed the ownership and operating arrangements of distribution networks and, in many countries, the role of the distribution system operator (DSO). In some countries, an electricity retailer or energy service provider entity is placed between the customer and the DSO. Smart grids enable increased interaction between DSO and customer through the provision of real-time energy usage information and pricing, which are important new tools for both DSOs and retailers. Experience gained through pilots and demonstrations can be applied to develop new business and market models for DSO/retailer-customer engagement. The most important aspect in the development of needed regulatory, business and market models is that benefits and risks associated with the deployment of smart grids must be shared with other stakeholders – upstream with other system operators and generators as well as downstream with end-users. Business models without shared costs and benefits will not be successful. Additional policy and regulation will be needed for DSOs to manage and utilise these relationships to meet system investment needs.

Smart grid, smart consumer policies

Electricity is consumed by a range of customers, including industrial, service/commercial and residential. In industrial and sometimes the commercial sectors, customer knowledge of energy management is high and technologies to enable demand response or energy efficiency are well known, mature and driven by cost savings. However, this is not the case at the residential level, where there is a need to rapidly expand business models, analysis and communication to enable much greater residential customer interaction with the smart grid.

Compared with customers in other industries, such as telecommunications, travel and retail, electricity consumers are typically not provided with either the service options or pricing information needed to manage their consumption. Providing these options and information can help costumers become smarter while delivering significant benefits to grid operators, including reduced costs. Smart grid customer policies fall into three groups: consumer feedback, pricing and customer protection.

This roadmap recommends the following actions:	***Milestones***
Collect and codify best practice from smart grid and smart metering pilot projects and increase study of consumer behaviour, use findings to improve pilot projects.	2011 to 2020
Expand pilots on automated demand response especially in service and residential sectors.	Continue over 2011 to 2050
Develop electricity usage tools and pricing practices that incentivise consumers to respond to changes in electricity markets and regulation.	Evolve approaches over time, largely completed by 2030
Develop new policies and protection mechanisms to control and regulate privacy, ownership and security issues associated with detailed customer usage behaviour information.	From 2011 to 2020
Develop social safety nets for vulnerable customers who are less able to benefit from smart grid pricing structures and are susceptible to remote disconnection functions made possible by smart grids.	From 2011 to 2015

Collect best practice on consumer feedback and use it to improve pilot projects

The principle behind consumer feedback policies is that making energy more visible enables customers to better understand and modify their behaviour. Consumer feedback can be provided across a continuum, from a monthly bill to instantaneous read-outs of consumption and prices, some of which are quite costly. A balanced and effective consumer feedback policy can be developed by considering: i) What information customers really need to make rational energy decisions?; and ii) What is the best form and medium to present this information?

Current consumer feedback pilot projects have only been able to motivate and discern short-term behaviour changes, because participants realise that the technology and services provided are temporary. Infrastructure changes, which deliver large and sustainable efficiency and demand response results, are obtained only from long-term or permanent programmes. This is one of many reasons why consumer feedback pilot project results vary radically. The design of pilot projects also makes it difficult to discern adaptive and infrastructure changes, resulting in overestimates or underestimates of long-term results. More rigorous and methodical research and evaluation is needed to identify the optimal method to deliver feedback and to understand better the interaction between consumer feedback and pricing or incentives (financial or other) and the effect of enabling technologies (*e.g.* automation) on results. These improved approaches can reduce other issues creating variability in pilot project results, including the prior history of consumer feedback policies, variety in customer types and preferences, and the specifics of the service options being piloted.

Additional research in this area should have three objectives: i) identify lessons for policy-makers from social science research on consumer feedback by collecting and comparing the results of advanced metering, real-time pricing and consumer feedback demonstration; ii) outline technologies proven to mobilise sustainable changes in energy consumer behaviour; and iii) establish a community of practice internationally to develop standard methods and analytic tools for estimating the consumer behaviour change benefits of smart grids.

Automated demand response

Many analysts believe that the full potential of smart grids can only be realised by creating a seamless and automatic interconnection between the network and the consumer installation – either by using some end-use devices that are pre-programmed by the consumer, or by using automated building management systems. Feedback with the customer would occur automatically within consumer-set parameters, in an extension of the feedback policies discussed above. There is a significant amount of research being carried out on processing and automation technologies that enable homeowners, building managers and business operators to programme end-uses to automatically adjust consumption and demand according to price or other signals. The potential for automated end-user demand and efficiency response are considerable and have been already proven in some situations. In California, several energy providers have collaborated with factories and building owners to configure energy management systems to curtail discretionary loads (lighting, elevators, heating, ventilation and air-conditioning) whenever hourly prices exceed pre-set levels.

Smart grid and smart metering pilot projects on automated demand response and energy efficiency offer best-practice lessons that need to be collected and incorporated into pilot programmes. There is significant interest in extending successful approaches found in the industrial and service sectors to the residential sector, but many aspects need to be investigated. Key research questions include:

- Is there an optimal mix of consumer feedback and automation technologies?
- What is the impact of ICT choices on automated DR?
- Which types of automated DR designs are most useful to different types of customers (households, businesses, industry)?

Determine best practice pricing policies

A range of pricing options can reflect actual generation and delivery costs, from static (non-time differentiated) to real-time pricing. The capability to deliver dynamic rather than static pricing is an important benefit of smart grids, but has raised fundamental questions about energy prices, including whether they should reflect real costs in real time, provide customers with choice and eliminate cross-subsidies. Dozens of smart customer pilot projects around the world have shown that time-differentiated pricing can reduce peak demand by an average of about 15%; adding technology on the customer side of the meter can more than double these impacts (Faruqui, 2010). This research shows a relationship between information and consuming behaviour, with more detailed and more frequent information yielding greater efficiency improvements and peak demand reductions.

The benefits to be delivered by smart customers who respond to pricing signals make up a large part of the business case for smart grid deployments. For example, the United Kingdom's national smart meter rollout is expected to reduce domestic electricity consumption by 3% and peak demand by another 5%, generating almost half of the USD 22 billion annual estimated savings – providing benefits to both consumers and utility stakeholders. Electricity providers in California and elsewhere estimate that demand response and energy efficiency benefits made possible by smart customers will be one-third to one-half of total benefits from smart grid deployment[24]

With flat-rate pricing, common to most retail markets globally, customers are charged the same price for electricity through out the day and the evening. The result is that customers are overcharged for some electricity (typically at non-peak times) and undercharged for some electricity (typically during peak times). Such pricing does not encourage customers to shift demand to different times, thereby reducing stress on the infrastructure when needed, but does provide a simple cost structure. The other end of the spectrum is real-time pricing, in which electricity is priced based on actual costs of generation, transmission and distribution. There is no overcharging or undercharging for electricity, but consumers may not be able to reduce electricity demand during peak times and therefore risk incurring higher costs. A third option for retail customers falls between these two extremes. Time-of-use (TOU) pricing mechanisms take advantage of the general predictability of electricity costs on a daily and seasonal basis. TOU pricing also reduces the risk for customers by providing certainty.

In deciding pricing policies for smart grid deployments, regulators must consider not only the pricing programme, but also the approach taken to communicate and deliver such changes to the customers. The following questions need to be considered:

- Should dynamic pricing be the default service or an optional service?
- Are there better alternatives to dynamic pricing that can yield equivalent demand response benefits, such as peak time rebates or direct load control, which may be easier to understand and less controversial?

24 These are estimated benefits usually based on extrapolation of pilot projects to large-scale rollouts. They include a number of assumptions on market penetration and capacity/energy impacts of pricing and service options.

- How much time differentiation in prices is needed to deliver demand-response benefits?
- What transitional policies are needed to help overcome customer inertia and risk aversion?

Transition strategies and policies are especially important considering opposition by some consumer advocates to smart metering deployments and associated pricing changes

More research is needed to examine how time-differentiated pricing can best induce behaviour-changing effects, taking account of such factors as the rate difference needed and the optimum number of time zones for consumer communication. Transition strategies to be studied include consumer communications schemes, shadow pricing, bill protection mechanisms and two-part rate designs.

Develop and implement consumer protection policies

The main consumer protection issues associated with smart grid deployments include: i) privacy, ownership and security issues associated with the availability of detailed customer energy consumption data; ii) customer acceptance and social safety net issues associated with new types of rates, especially dynamic pricing; and iii) consumer protection issues associated with remote disconnection functions made possible by smart grids. These consumer issues should be addressed within the overall context of smart grid design and deployment planning; otherwise there is a very real potential for some customers to react adversely or even be harmed.

Customer data privacy, ownership and security issues are a leading concern of consumer and privacy advocates. Smart grid and smart meter deployments create large amounts of detailed customer-specific information, while energy providers gain a new medium for customer interaction. Policy questions needing attention include:

- Who owns the customer's data, and how is access to and use of this data regulated?
- Who guarantees privacy and security of customer data (*e.g.* against risk of surveillance or criminal activity)?
- Will sale or transfer of customer data be allowed, and under what terms and to whose benefit?
- In jurisdictions with retail choice, are measures needed to ensure competing electricity providers have access to customer data on the same terms as the incumbent utility?

Many regions are beginning to address these issues, as evidenced by rules relating to consumer data recently proposed in Ohio[25] and by the European Commission's expert group on regulatory recommendations for safety, handling and protection of data (part of the EU's Task Force on Smart Grids),[26] among other projects. The Office of Gas and Electricity Markets (OFGEM) in Great Britain is proposing to have an independent organisation (Data Communications Company) to access and store consumer data, and to disseminate only the basic required data to the relevant parties for billing or usage purposes. Best practices are coming to light in these and other project, and work in this area must continue.

Customer acceptance and social safety net issues

Customer acceptance and social safety net issues are of key concern where consumer advocates warn of rate increases and adverse consequences, especially for vulnerable consumers or those who cannot adjust their usage patterns as a result of pricing. Additionally, smart grids could allow quicker disconnection of service and negatively impact vulnerable consumers such as low-income groups, pensioners and the handicapped. These groups may be disadvantaged by dint of their consumption level or inability to change behaviour, or they may be subject to new rate burdens that are not commensurate with their opportunity to benefit.

The development of smart metering and dynamic pricing technology also introduces new pressures and opportunities for rate regulation. Charging customers the same electricity price all hours of the year when the true cost of electricity changes constantly may not be good regulatory practice – if it is possible to deploy the technology in a cost-effective way to reflect these variations.

There is also some evidence that smaller customers, including low-income households, have been paying more than their fair share for electricity, while larger users with big, temperature-sensitive loads may be driving up electricity costs for

25 www.puco.ohio.gov/PUCO/Consumer/Information.cfm?id=10032

26 http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/expert_group2.pdf

everyone. From this viewpoint, smart metering and dynamic pricing provide an opportunity to remove hidden rate subsidies that until now have burdened smaller customers. Further, in many pilot projects, including the PowerCents DC project in Washington, DC, lower-income customers have signed up for the programme at higher rates than others, and have responded to price signals.

Further research is needed to identify the full range of consumer protection policies and make recommendations to governments on smart grid-related consumer protection issues.

Building consensus on smart grid deployment

This roadmap recommends the following actions:	*Milestones*
Accelerate education and improve understanding of electricity system customers and stakeholders (including energy utilities, regulators and consumer advocates) to increase acceptance for smart grid deployments.	From 2011 to 2020
Develop technological solutions in parallel with institutional structures within the electricity system to optimise overall operations and costs.	From 2011 to 2020 (with continued evolution to 2050)

As smart grid technologies are deployed, electricity systems will become more customer-focused, but customer behaviour is difficult to predict. A long-term process of customer education and improved understanding of customer response is needed to consolidate technology and user interactions across the electricity system. Energy utilities, regulators and consumer advocates all have a role in building awareness. Ultimately all investments are paid for by customers, so those deploying smart grids should be able to demonstrate clearly how costs will be recovered and how investment will benefit the customer. Customers must be significantly engaged in the planning and deployment of smart grids, at demonstration stage and at full-scale rollout. So far, customers have seldom been at the table during the smart grid planning process.

A positive example of a good customer engagement strategy can be found in ENEL's Telegestore project in Italy. During the rollout of 33 million smart meters, ENEL dedicated time to educating the public through town hall meetings and discussions with consumer protection groups that had voiced concerns over the collection of data about consumer energy habits. While assuaging people's doubts, Enel was able to explain that most customers' bills would go down because of smart meters, helping increase customer loyalty.[27]

The demonstration and deployment of new technologies involves some level of risk. The risk must be analysed and addressed jointly by stakeholders; technology risks can be best addressed by the technology providers and system operators, while policy and market risks must be considered with regulator and customer involvement. By phasing demonstration and deployment carefully while considering and adapting policy, regulation and institutional structures, risks can be minimised and projects will be more broadly accepted. It can be argued that risks associated with smart grid development, demonstration and deployment will be lower than the risk of not addressing the coming changes and needed investment in the electricity system.

27 www.smartgridaustralia.com.au/index.php?mact=News,cntnt01,detail,0&cntnt01articleid=277&cntnt01returnid=69

International collaboration

This roadmap recommends the following actions:	*Milestones*
Expand smart grid collaboration; particularly related to standards and sharing demonstration findings in technology, policy, regulation and business model development.	Targeted effort from 2011 to 2015. Ongoing to 2050
Link with electricity system technology areas that are not exclusively focused on smart grids.	From 2011
Expand capacity-building efforts in rapidly developing countries by creating smart grid roadmaps and undertaking targeted analysis tailored to contexts such as rural electrification, island systems and alternative billing approaches.	Focused initiatives to 2030. Ongoing to 2050

Expand existing international collaboration efforts

International collaboration enables the sharing of risks, rewards and progress, and the co-ordination of priorities in areas such as technology, policy, regulation and business models. In order to reach the goals set out in this roadmap, smart grids need to be rapidly developed, demonstrated and deployed based on a range of drivers that vary across regions globally. Many countries have made significant efforts to develop smart grids, but the lessons learned are not being shared in a co-ordinated fashion. Major international collaboration is needed to expand RDD&D investment in all areas of smart grids – but especially in standards, policy, regulation and business model development. These efforts will require the strengthening of existing institutions and activities, as well as the creation of new joint initiatives.

Standards play a very important role in the development of technology. By providing common design protocols for equipment, they can increase competition, accelerate innovation and reduce costs. International collaboration on standards is vital to ensure that the needs of various regions are included, and to reduce repetition and overlap in the development of standards. Several organisations are already working to harmonise standards; continued and increased efforts are needed as discussed earlier in the section on technology development.

There is an urgent need to develop a significant number of commercial-scale demonstration projects and share the results among electricity system stakeholders. Projects are being developed at a national or regional level, but the reporting of data, regulatory approaches, financial mechanisms, public engagement experiences and other aspects need to be shared globally. The International Smart Grid Action Network (ISGAN), which has been created to address this need, will serve an important role as a platform and forum for compiling global efforts, performing analysis and developing tools for stakeholders. The Global Smart Grid Federation (GSGF), APEC Smart Grid Initiative, the European Electric Grid Initiative (EEGI) and European Energy Research Alliance Joint Programme (EERA JP) on Smart Grids are examples of global or regional initiatives that need to build on and strengthen their collaboration as they monitor the implementation of the actions and milestones in this roadmap.[28]

Create new collaborations with other electricity system technology areas

Smart grids include technology areas, such as renewable energy resources and demand response, which are not exclusively associated with, but are related to, smart grids. Some of these technology areas were being studied long before the term smart grid was developed, and therefore may offer solutions to problems that smart grids hope to address. Collaboration with these electricity system technology areas has the opportunity to accelerate the useful deployment of smart grids and avoid repeating past development work.

An ideal way to collaborate across these electricity system technology areas is through the IEA Implementing Agreements (IAs).[29] Of the 43 IAs, 11 focus on electricity system issues (Table 9); these are co-ordinated under the Electricity Co-ordination

28 Web addresses for these organisations can be found on p. 48.

29 IEA Implementing Agreements are multilateral technology initiatives through which IEA member and non-member countries, businesses, industries, international organisations and non-government organisations share research on breakthrough technologies, fill existing research gaps, build pilot plants and carry out deployment or demonstration programmes.

Group (ECG). These IAs develop and deliver broad knowledge about the electricity system as a whole along the entire value chain on an international level. The ECG enables those working under related IAs to learn what others are studying and determine ways to analyse aspects that cut across several technology areas; this is especially relevant for smart grids. The need for an implementing agreement focus on smart grids is currently under consideration.

Table 9. Electricity sector focus for IEA ECG Implementing Agreements

<table>
<tr><th colspan="4">Smart grids</th></tr>
<tr><th>Generation</th><th>Transmission</th><th>Distribution</th><th>End-user</th></tr>
<tr><td></td><td></td><td colspan="2">Demand-Side Management</td></tr>
<tr><td></td><td></td><td></td><td>Efficient Electrical End-Use Equipment</td></tr>
<tr><td></td><td colspan="2">Electricity Networks Analysis, Research & Development</td><td></td></tr>
<tr><td colspan="3">Energy Conservation through Energy Storage</td><td></td></tr>
<tr><td colspan="4">IEA GHG R&D Programme</td></tr>
<tr><td>Hybrid and Electric Vehicles</td><td></td><td colspan="2">Hybrid and Electric Vehicles</td></tr>
<tr><td></td><td colspan="2">High-Temperature Superconductivity on the Electric Power Sector</td><td></td></tr>
<tr><td colspan="2">Ocean Energy Systems</td><td></td><td></td></tr>
<tr><td colspan="3">Photovoltaic Power Systems</td><td></td></tr>
<tr><td colspan="4">Renewable Energy Technology Deployment</td></tr>
<tr><td colspan="2">Wind Energy Systems</td><td></td><td></td></tr>
</table>

Note: The diagram indicates the primary area of the electricity system where the IA focuses. Most IAs engage with sectors beyond those indicated. Website addresses can be found on page 48.

Smart grid collaboration and developing countries

Smart grids can provide significant benefits for developing countries that are building up electricity system infrastructure. In some cases, the solutions applied in developed countries will be appropriate; in others, targeted approaches will be required. Collaboration between developing and developed countries can provide the basis for identifying problems and solutions.

Some countries have already started to pursue smart grid activities and some of these efforts include international collaboration. However, other countries need to be more actively engaged, through information-sharing efforts about the benefits and best practices of smart grids. Roadmaps tailored to a set of needs common to many developing countries – such as rural electrification and island-based systems – would provide much value. These roadmaps could identify the barriers to wider technology deployment and the means to overcome them, including regulation, policy, finance, and targeted technology development and business models. Additionally, targeted energy system modelling, standards development, legislation precedents and capacity building would help identify and prioritise developing country specific needs and advance technology deployment (Bazilian, 2011). International platforms such as ISGAN and GSGF, as well as the United Nations Industrial Development Organisation and other organisations focusing on developing country needs, could be used to help capacity-building efforts and to share lessons learned and experiences.

Conclusion: near-term roadmap actions for stakeholders

Smart grids are a foundational investment that offer the potential to substitute efficient use of information for more conventional "steel-in-the-ground" investments in the electricity system, at considerable cost savings to consumers, as demonstrated by early results of pilot projects. Smart grids will also change how power system planning is done, and how wholesale and retail electricity markets are co-ordinated. The information collected through smart grids will not only empower customers to manage their electricity consumption but will enable electricity system operators to better understand and meet users' needs.

The roles of the government and the private sector are often misunderstood, at times by themselves and often by each other. The broadness and complexity of the electricity system (technologically and from a regulatory and market perspective), and its importance to society in general, increase the necessity to understand who should perform the actions outlined in this roadmap. Neither the government alone, nor the private sector alone, can accomplish the goal of modernising the electricity system. Collaboration is vital.

Below is a summary of the actions by key electricity system stakeholders, presented to indicate who should take the lead in such efforts. In most cases, a broad range of actors will need to participate in each action.

Summary of actions led by stakeholders

Lead stakeholder	*Action*
Electricity generators	Utilise flexibility and enhancements delivered by smart grids to increase use of variable generation to meet demand growth and decrease emissions.
Transmission and distribution system operators	Develop business models along with government and regulators that ensure all stakeholders share risks, costs and benefits.
	Lead education in collaboration with other stakeholders on the value of smart grids, especially with respect to system reliability and security benefits.
	Promote adoption of real-time energy usage information and pricing to allow for optimum planning, design and operation of distribution and transmission systems in a co-ordinated fashion.
	Demonstrate smart grids technology with business models that share risks, benefits and costs with customers in order to gain regulatory approval and customer support.
Government and regulators	Collaborate with public and private sector stakeholders to determine regulatory and market solutions that can mobilise private sector investment in all electricity system sectors.
	Recognise that smart grid deployments should reflect regional needs and conditions – a "one-size-fits-all" does not apply to the deployment of smart grids.
	Plan for evolution in regulation along with technology development – new technologies will both offer and need new regulatory options.
	Invest in research, development and demonstration (RD&D) that address system-wide and broad-range sectoral issues, and that provide insights into behavioural aspects of electricity use.
Technology and solution providers	Deliver full technology solutions to system operators through partnership with others in the value chain to address concerns with technology system integration, long-term post-installation support, and security and reliability.
	Create a strategy and develop standards in participation with industry and government stakeholders on an international level to ensure interoperability of system components and reduce risk of technology obsolescence.

Lead stakeholder	*Action*
Consumers and consumer advocates	Develop understanding of electricity system reliability, quality, security and climate change benefits of smart grids. Help develop regulatory and market solutions that share investment risks, costs and benefits with all consumers. Actively engage in developing system demonstrations and deployments in order to ensure consumer contribution to and benefit from future electricity systems and markets, while ensuring consumer protection.
Environmental groups	Support the development of smart grids necessary for a range of clean energy technology deployments such as wind, solar and electric vehicles.
International governmental organisations	Support the RD&D of smart grid solutions for developing countries through targeted analysis, roadmapping exercises and capacity building. Support international collaboration on and dissemination of smart grid RD&D, including business and regulatory experiences.

Glossary

Critical peak pricing (CPP): A tariff structure in which time-of-use prices are in effect except for certain peak days, when prices may reflect the costs of generating and/or purchasing electricity at the wholesale level.

Cyber security: Effective strategies for protecting the privacy of smart grid related data and for securing the computing and communication networks that will be central to the performance and availability of the envisioned electric power infrastructure.

Demand response (DR): Changes in electricity usage by customers in response to alterations in the price of electricity, or incentives designed to induce lower electricity use when system reliability is jeopardised or to increase consumption when generation from renewable sources is high. Demand response can be performed manually by the end-user or automatically based on predefined settings.

Distribution: The transfer of electricity from the transmission system to the end-use customer.

Electric utilities: Enterprises engaged in the production, transmission and/or distribution of electricity for use by the public, including investor-owned electric utility companies; cooperatively owned electric utilities; and government-owned electric utilities.

Flexibility: The capability of a power system to maintain reliable supply by modifying production or consumption in the face of rapid and large imbalances, such as unpredictable fluctuations in demand or in variable generation. It is measured in terms of megawatts (MW) available for ramping up and down, over time.

Generation: The process of producing electric energy or the amount of electric energy produced by transforming other forms of energy, commonly expressed in kilowatt hours (kWh) or megawatt hours (MWh).

Real-time pricing (RTP): A tariff structure in which electricity prices may change as often as hourly (exceptionally more often). A price signal is provided to the user on an advanced or forward basis, reflecting the utility's cost of generating and/or purchasing electricity at the wholesale level.

Renewables: Resources that derive energy natural processes that are replenished constantly. Renewable energy resources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action and tidal action.

Time-of-use pricing (TOU): A tariff structure in which electricity prices are set for a specific time period on an advance or forward basis, typically not changing more often than twice a year. Prices paid for energy consumed during these periods are pre-established and known to consumers in advance, allowing them to vary their usage in response to such prices and manage their energy costs by shifting usage to a lower cost period or reducing their consumption overall.

Transmission: The transfer of bulk energy products from where they are produced or generated to distribution lines that carry the energy products to consumers.

Variable renewables: Technologies such as wind, solar PV, run of river hydro and tidal where production of electricity is based on climatic conditions and therefore cannot be dispatched based on a need for additional power alone.

Regional definitions

Africa

Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo,Côte d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, the United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia and Zimbabwe.

Central and South America (CSA)

Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, the Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts-Nevis-Anguilla, Saint Lucia, St. Vincent-Grenadines and Suriname, Trinidad and Tobago, Uruguay and Venezuela.

China

China refers to the People's Republic of China including Hong Kong.

Middle East (MEA)

Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the United Arab Emirates and Yemen. For oil and gas production, it includes the neutral zone between Saudi Arabia and Iraq.

Other developing Asia

Afghanistan, Bangladesh, Bhutan, Brunei, Chinese Taipei, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Malaysia, Maldives, Mongolia, Myanmar, Nepal, New Caledonia, Pakistan, Papua New Guinea, the Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Vietnam and Vanuatu.

Economies in transition

Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, the Federal Republic of Yugoslavia, the former Yugoslav Republic of Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

OECD Europe

Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey and United Kingdom.

OECD North America

Canada, Mexico and United States.

OECD Pacific

Australia, Japan, Korea and New Zealand.

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NIST (National Institute of Standards and Technology) (2010), *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0*, Office of the National co-ordinator for Smart Grid Interoperability.

List of relevant websites

Department of Energy – Smart Grid:
www.oe.energy.gov/smartgrid.htm

European network for the Security of Control and Real-Time Systems (ESCoRTS):
www.escortsproject.eu/

European Technology Platform (ETP) for Europe's Electricity Networks of the Future:
www.smartgrids.eu/

Global Smart Grid Federation:
www.globalsmartgridfederation.org/

IEEE Smart Grid: smartgrid.ieee.org/

International Electricity Infrastructure Assurance:
www.ieiaforum.org

International Smart Grid Action Network (ISGAN):
www.iea-isgan.org

Japan Smart Community Alliance:
www.smart-japan.org/english/tabid/103/Default.aspx

Korean Smart Grid Institute:
www.smartgrid.or.kr/eng.htm

National Institute of Standards and Technology (NIST) Smart Grid: www.nist.gov/smartgrid/

The NETL Smart Grid Implementation Strategy (SGIS): www.netl.doe.gov/smartgrid/

Smart Grid Information Clearinghouse:
www.sgiclearinghouse.org/

IEA Electricity based Implementing Agreements

Demand-Side Management (DSM):
www.ieadsm.org/

Electricity Networks Analysis, Research & Development (ENARD): www.iea-enard.org/

High-Temperature Superconductivity on the Electric Power Sector (HTS):
www.superconductivityIEA.org

Energy Conservation through Energy Storage (ECES): www.energy-storage.org

Hybrid and Electric Vehicles (HEV): www.ieahev.org

Efficient Electrical End-Use Equipment (4E's):
www.iea-4e.org

IEA GHG R&D Programme (GHG R&D):
www.ieaghg.org

Ocean Energy Systems (OES): www.iea-oceans.org/

Photovoltaic Power Systems (PVPS):
www.iea-pvps.org

Wind Energy Systems (Wind): www.ieawind.org

Renewable Energy Technology Deployment (RETD):
www.iea-retd.org

Technology Roadmaps Smart Grids

2010

2015

2020

2025

2030

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